A Study of Ground-Level Air Pollutant Emissions from Airport Mobile Sources

by

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ABSTRACT

Annual emission estimations and dispersion analysis were carried out for airport mobile sources (aircraft, ground support equipment, and on-road vehicles) at a major U.S. airport for recent years and 2010. The focus was to find various ways to reduce emissions and/or improve air quality at major airports and suggest information and technology which will assist and improve future studies and air quality evaluations. The air pollutant species included in this study are HC, CO, NO_X, SO_X for emission estimation and CO, NO_X, and SO_X for dispersion analysis.

The annual emission estimations for recent years showed that the aircraft were responsible for the majority of air pollutant emissions except for CO. The result from dispersion analysis suggested that emissions from ground support equipment may have significant impact on air quality around the gates. The annual emission estimations for 2010 showed that the average emissions from aircraft main engines per LTO cycle would decrease except for NO_X. However, the total amount of emissions would be greater (except for HC), if the air traffic increases as predicted.

A significant emission reduction can be achieved by practicing reduced-engine taxiing during aircraft taxi-out, improving the aircraft taxi efficiency, and replacing the conventional ground support equipment with electric powered counterparts, or fixed gate support systems.

The study suggests that future evaluations should pay attention to non-jet and jet aircraft on an equal basis. Creating databases for ground support equipment, aircraft engine emissions (SO_X and PM) will also improve the analysis.

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Nomenclature

Symbol		Meaning
C	=	point concentration at receptor [μg/m^3]
E	=	pollutant emission [g]
EF	=	emission factors [kg/hr]
EI	=	emission index [g pollutant/kg fuel]
FF	=	fuel flow rate [kg/s]
H	=	effective height of emissions [m]
H_{mix}	=	height of mixing zone [ft]
LTO	=	number of LTO cycles
Q	=	mass flow of contaminants from receptor [μg/s]
T	=	time-in-mode [min]
u	=	wind speed [m/s]
σ_y, σ_z	=	standard deviation of plume concentration distribution [m]

Subscript

app	=	approach operating mode
c/o	=	climb-out operating mode
dapp	=	approach operating mode for default condition
dc/o	=	climb-out operating mode for default condition
i	=	pollutant i
j	=	aircraft type j
k	=	aircraft operating mode k
p	=	ground support equipment or auxiliary power unit p
q	=	ground support equipment and auxiliary power unit group q
T	=	total
x,y,z	=	right-handed Cartesian coordinate system [m]

1. Introduction

1.1 Background and Study Objectives

Ground-level air pollution emission is one of the main environmental issues related to airport operation among noise, waste management, and land use. In recent years regulatory agencies and other environmental groups have voiced their concern over aircraft emissions. According to the United States Environmental Protection Agency (EPA), aircraft main engines of all commercial, military, and general aviation flights are responsible for about one percent of the total United States ground-level emissions from mobile sources. In general, the contribution from aircraft engines is higher in urban areas where the demand for commercial flights is greater.

The remaining two groups of mobile emission sources at airports are ground support equipment and access vehicles. Although ground support equipment is responsible for a small percentage of the air pollutant emissions in the entire metropolitan area, their contribution to the local air quality should not be ignored.

The significance of emissions from all these sources is expected to increase as the projected air travel in the coming decades increases and the relative contribution of the other sources declines under the pressure of progressively more stringent emission control programs. Preservation of human health is the primary concern in evaluating and controlling emissions from any source. The secondary concern is the protection of public welfare.

The purpose of this study is to analyze characteristics of ground level air pollution emissions from airport mobile sources in order to 1) find various ways to reduce emissions and/or to improve air quality at major airports in general public access areas, and 2) suggest information and technology which will assist and improve future studies and air quality evaluations. It was hoped to seek ways to compliment the development of commercial aviation and minimize the environmental impact of this development.

1.2 Airport Emissions and Public Health

1.2.1 Airport Emissions

A number of air pollutants, including the major criteria pollutants, are associated with emissions from airports. Some air pollutant species emitted from mobile sources include volatile organic compounds, carbon monoxide, oxides of nitrogen, sulfur oxides, and particulate matter. Polycyclic aromatic hydrocarbons are found in particulate emissions and certain volatile organic compounds. There is no direct ozone emissions from any mobile sources, however, oxides of nitrogen are the important precursors. The ozone concentrations are controlled by various factors such as the amount of oxides of nitrogen, volatile organic compounds, and the strength of ultraviolet rays. The health and environmental effects of these pollutants are described below.

1.2.2 Health Effect of Air Pollutants

Ozone (O_3)

Detrimental health effects are induced by short-term exposures (1 to 2 hours) to ozone, generally while individuals are engaged in moderate or heavy exertion, and by prolonged exposures (6-8 hours) to ozone, typically while individuals are engaged in moderate exertion. Acute health effects of ozone, defined as those effects induced by short-term and prolonged exposures to ozone, include transient pulmonary function responses, transient respiratory symptoms, effects on exercise performance, increased airway responsiveness, increased susceptibility to respiratory infection, increased hospital admissions and emergency room visits, and transient pulmonary inflammation.

Acute health effects have been observed following prolonged exposures during moderate exertion at concentrations of ozone as low as 0.08 PPM. Active children, outdoor workers who engage in outdoor activities, and individuals with preexisting respiratory diseases, such as asthma or chronic obstructive lung disease, are at increased risk of acute health effects.

Chronic health effects of ozone are defined as those effects induced by repeated long-term exposure to ozone. These effects include chronic inflammation and structural damage to lung tissue and accelerated decline in baseline lung function. While there are many ambiguities regarding chronic health effects and cause-and-effect relationships tend to be uncertain, currently available information provides, at a minimum, a biologically plausible basis for the possibility that repeated lung inflammation associated with ozone exposure may result in sufficient damage to respiratory tissue over a lifetime resulting in a reduced quality of life.

Carbon Monoxide (CO)

Carbon monoxide is an odorless, colorless gas that is a by-product of incomplete combustion. Carbon monoxide reduces the oxygen carrying capacity of blood and weakens the contractions of the heart. Therefore, the amount of blood pumped to various parts of the body is reduced and less oxygen is available to the muscles and various organs when individuals are exposed to carbon monoxide. In a healthy person, this effect can significantly reduce the ability to perform physical exercise. In an individual with chronic heart disease, this effect can threaten the overall quality of life, since the system of such an individual is unable to compensate for the decrease in oxygen

Nitrogen dioxide (NO_2)

A healthy individual experiences respiratory problems when exposed to high levels of nitrogen dioxide for short duration (less than 3 hours). Individuals with asthma are especially sensitive; changes in airway responsiveness have been observed in some studies of exercising asthmatics exposed to relatively low levels of nitrogen dioxide. Studies also indicate a relationship between indoor nitrogen dioxide exposure and increased respiratory illness rates in young children, although there is no definitive result available. Many animal studies suggest that nitrogen dioxide impairs respiratory defense mechanisms and increases susceptibility to infection.

It is suggested that chronic exposure to nitrogen dioxide could lead to adverse health effects in humans. Several animal studies show that chronic exposure to relatively low nitrogen dioxide pollution levels may cause structural changes in the lungs.

However, specific levels and exposure duration of nitrogen dioxide that is likely to cause such effects in humans have not yet been determined.

Sulfur Dioxide (SO_2)

Major physiological effects of sulfur dioxide exposures are characterized by changes in the mechanical function of the upper airways, such as an increase in nasal flow resistance and decrease in nasal mucus flow rate.

Some studies have shown that moderately exercising individuals with asthma experienced significant bronchoconstriction (airway narrowing) shortly after they were exposed to 0.5 to 1.0 PPMV sulfur dioxide. This effect was not observed in healthy individuals. Children and adults with mild-to-moderate asthma are at the greatest risk for respiratory effects induced by short-term sulfur dioxide exposures. Individuals with more severe asthma would be at lower risk since their low tolerance for exercise would deter them from engaging in activities which have sufficient intensity to cause such effects.

Particulate Matter (PM)

The health effects reported to be associated with ambient particulate matter include premature mortality, aggravation of respiratory and cardiovascular disease, changes in lung function and increased respiratory symptoms, changes to lung tissues and structure, and altered respiratory defense mechanisms. Individuals with asthma, respiratory disease and cardiovascular diseases, as well as the elderly and children appear to be at greater risk to such effects.

Volatile Organic Compounds (VOC's)

Organic chemicals emitted into the atmosphere, typically described as volatile organic compounds or hydrocarbons, are a result of evaporation or incomplete fuel combustion. Some organic chemicals have little or no known direct health effect. Others, such as benzene, are carcinogens. Some individuals have experienced symptoms such as eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory impairment soon after they were exposed to some organic chemicals.

Air quality standards for non-methane hydrocarbons have been promulgated to achieve standards for ozone, therefore the standard is not based on the health effects of the organic chemicals themselves.

1.2.3 Environmental Effect of Air Pollutants

Ozone (O_3)

Ground-level ozone interferes with the ability of plants to produce and store food. Growth, reproduction and overall plant health are compromised. Further, weakened trees and other plants become more susceptible to disease, insect attacks, and harsh weather. Agricultural yields for many economically important crops, such as soybean, kidney bean, wheat, and cotton, may be reduced, and the quality of some crops may be damaged, reducing their market value. Plant leaves can be killed or damaged when exposed to ground-level ozone and they fall off the plants too soon, or become spotted or brown. These effects can significantly decrease the natural beauty of socially important communities and the associated quality of lifestyle.

Carbon Dioxide (CO_2)

The greenhouse effect and global warming are results from the absorption and reradiation of infrared energy by trace gases. Carbon dioxide is one of the greenhouse gases among water vapor, methane, ozone, and some man-made substances such as chlorofluorocarbons or CFCs.

Concentration of carbon dioxide, just like other greenhouse gases (excluding water vapor), has been affected by human activities. Combustion of fossil fuels as well as the clearing of tropical forests increase carbon dioxide emissions. Although relative radiative effectiveness of carbon dioxide is small compared to methane and some CFCs, relative contribution from carbon dioxide to global warming was estimated to be 55% in 1990.

Oxides of Nitrogen (NO_X)

Oxides of nitrogen are important precursors to ozone. Emitted from hydrocarbon combustion at high temperatures, oxides of nitrogen react with gaseous hydrocarbons to form ozone. "Smog" refers to the mixture of ozone and oxides of nitrogen.

Oxides of nitrogen also play a role in the formation of acid rain. Some observed effects caused by acid rain are decay of building materials, damage in trees at high elevations, and surface water acidification.

Furthermore, oxides of nitrogen affect visibility since the gas itself is brown and contributes to the formation of particles in the atmosphere. The health and environmental effects due to the particles are discussed in the particulate matter sections.

Particulate Matter (PM)

There are two primary environmental effects of particulate matter: visibility and soiling. The visibility impairment can be observed in a major metropolitan area on a hazy day. It is caused by either the direct emission of particles or the formation of particles from the oxides of nitrogen and volatile organic compounds. The soiling effect of particles is observable on objects such as buildings, monuments, and vehicles.

Volatile Organic Compounds (VOC's)

While the principal environmental effect of volatile organic compounds is their contribution to the formation of ozone, there is a wide variety of environmental effects caused by these organic chemicals depending on the chemical nature and the quantity present in the atmosphere. At high levels, damages on plants, crops, and buildings have been observed. And if chlorine is contained in the chemicals they can contribute to stratospheric ozone depletion.

The contributions from volatile organic compounds to particle formation are made either directly through cooling down of hot engine exhaust or indirectly through chemical conversion and condensation.

1.3 Study Overview

The study focused on the evaluation of recent-year ground-level air pollution at a major airport in the United States. A limited investigation for an assumed future scenario was also conducted to achieve the objectives. There were two main techniques used in this study: annual emissions estimation and dispersion modeling. The purpose of annual emissions estimation was not only to estimate the amount of total pollutants emitted from airport mobile sources, but also to determine the contributions from different types of sources. Once the annual emissions were estimated, the movement of the pollutants was simulated by intra-airport dispersion modeling. This dispersion analysis allowed the visualization of the pollutant concentrations on an hourly basis, given specific operational and meteorological conditions. It also suggests the limitations and factors that influence the result. Ultimately it was hoped that the findings will help improve air quality studies in the future.

It was found that there were many site specific variables involved in these methods and a difficulty in conducting a nationwide study was being able to incorporate all the facility level information. While the intention was not to target any specific airport, it seemed appropriate to choose a single facility so that a reasonable accuracy and detail of analysis could be maintained. A model airport must represent some common characteristics of a nation's busy airports which have attracted attention for their air pollution emissions issues. The following criteria was used to select a model airport:

1) The model airport must be located in an ozone non-attainment area.
2) The model airport must be the major airport in the region, and one of the nation's top airports.
3) The main traffic of the model airport must be commercial flights.
4) The model airport should be served by various air carriers and should not be a main hub for any giant U.S. carriers.
5) Increase in traffic must be expected at the model airport in the future.

Logan International Airport in Boston satisfied all five criteria and was local to the Massachusetts Institute of Technology, making it an ideal candidate as the model airport. This study was not conducted in conjunction with the Massachusetts Port Authority. Assumptions and methodologies must be carefully reviewed before any comparison of this study and the official environmental impact statement and/or an annual environmental analysis is made.

Logan International Airport

Logan International Airport is a major airport located in the Boston-Lawrence-Worcester serious ozone nonattainment area. It is the United States' seventeenth busiest airport and the world's twenty-sixth busiest airport based on passenger volume. There are approximately 600 daily departures. The airport boundary encompasses approximately 2,400 acres in East Boston, Massachusetts, situated within a few miles of the Boston downtown area. The airport is currently served by over 55 scheduled and non-scheduled airlines including eight major domestic carriers and sixteen foreign carriers.

The airfield is comprised of five runways, fourteen miles of taxiway, and 237 acres of concrete and asphalt apron. The planned expansion of the airport includes the construction of a new runway on the southwest side of the airport and several additional taxiways.

The close vicinity to downtown and residential areas, and location in the bay, contribute to the fact that Logan International Airport is one of the most constrained airports in the country. Nevertheless, an increase in air traffic is predicted in the coming decades at the airport.

2. Annual Emissions Estimation

The main focus of this study is the emissions from aircraft main engines. Therefore, the most detailed attention was paid to the preparation of the emissions estimation from aircraft main engines. Three other sources, the ground support equipment, the auxiliary power units of the aircraft, and on-road vehicles on the airport access road, were incorporated to determine the relative significance of the sources in relation to aircraft main engines. The annual emissions estimations from aircraft engines, ground support equipment, and auxiliary power units were prepared by a custom written FORTRAN program while the emission estimations from on-road vehicles were prepared with the FAA's Emission Dispersion and Modeling System (EDMS). Some details of EDMS are discussed in chapter 3. The procedural details of the emission estimations for each category of sources is described in the following sections.

2.1 Aircraft Main Engines

The emissions from aircraft engines that affect the ground level pollutant concentrations are associated with the landing and takeoff cycle, or LTO. The cycle begins when the aircraft enters the mixing zone as it approaches the destination airport on its descent from cruising altitude. The cycle continues as the aircraft lands and taxis to the gate. Some time later, the aircraft taxies back out to the runway for subsequent takeoff and climb-out. The LTO cycle is completed when the aircraft leaves the mixing zone as it climbs back to cruising altitude. Thus, approach, taxi-in, taxi-out, take-off, and climb-out are the five specific operating modes in an LTO cycle. The EPA's basic methodology for aircraft emissions estimation uses the LTO cycle as the measure of aircraft activity at a given airport.

The following six steps were performed to prepare the annual emissions estimation from aircraft main engines.

1) Determination of the height of mixing zone to be used to define an LTO cycle.
2) Estimation of the time-in-mode for each LTO operating mode.
3) Determination of the fleet make-up at the airport and the number of LTO cycles for each aircraft model.
4) Determination of the engine model(s) for each aircraft model included in the fleet make-up.
5) Selection of the emission factors for each aircraft engine included in step 4.
6) Estimation of the annual emissions based on the airport activity, time-in-mode, and aircraft emission factors.

The above steps are essentially identical to the EPA's methodology; the details of which are described in the following sections. In general, an attempt was made to incorporate more specific, less generalized information, when possible, in order to prepare a more accurate result.

2.1.1 Time-in-Mode Estimation

An LTO cycle consists of the five operating modes described in the previous section. The time-in-mode is the duration of each operating mode, usually expressed in minutes. The default time-in-mode for various categories of aircraft are provided by the EPA. Of the five operating modes, take-off is the most standardized operation. It is characterized primarily by full-throttle setting and typically lasts until the aircraft reaches between 500 and 1000 feet above ground level when the throttle setting is reduced and the climb-out mode begins. This transition height is fairly standard and does not vary much from location to location or among aircraft categories. Thus, for the take-off operation, the default time-in-mode was used for all categories of aircraft.

The duration in approach and climb-out largely depends on the height of the local mixing zone. Since the default time-in-mode assumes the default mixing height of 3000 feet, an adjustment was made to accommodate the local mean annual mixing height of 2,100 feet as follows:

Approach: $$T_{app} = T_{dapp} \cdot \frac{H_{mix}}{3000} \tag{2.1}$$

Climb-out: $$T_{c/o} = T_{dc/o} \cdot \frac{H_{mix} - 500}{2500} \tag{2.2}$$

The equation 2-2 assumes that the transition from take-off mode to climb-out mode takes place when the aircraft reaches an altitude of 500 feet.

The time-in-modes for taxi-in/idle and taxi-out/idle operations are most variable because they depend on the size and layout of the airport, the amount of traffic on the ground, and the active runway locations at the particular time. However, the default values were assumed in this study. A limited monitoring of the airport ground traffic showed that the default value provided by the EPA is somewhat 'reasonable' for at least commercial jet taxi-out/idle time. The limited taxi time information as provided by the FAA shows average taxi-in/idle time is also somewhat 'reasonable'.

2.1.2 Fleet Make-up and Number of LTO cycles

The actual numbers of LTO cycles at U.S. airports are summarized and published by the Department of Transportation each year. This publication called *Airport Activity Statistics of Certificated Air Carriers* covers all U.S. carriers with at least one aircraft that has more than 60 passenger seats or a maximum cargo capacity above 18,000 pounds. Table 7 of this publication lists the number of LTO cycles for each aircraft model for each air carrier. The statistics for twelve months ending December 31, 1998 was the latest issue available at the time of the study and was used to determine the number of LTO cycles for all U.S. carriers included in the statistics.

The aircraft that are not included in the statistics are the aircraft owned and operated by foreign air carriers, the aircraft owned by U.S. air carriers that perform commuter and on-demand operations, general aviation aircraft, and military aircraft. The May 1998 *Monthly Airport Traffic Summary* prepared by the Massachusetts Port Authority shows that 37.6% of the total flight operations at Logan International Airport in the first five months of 1998 were domestic regional/commuter flights and 9.5% were international flights. Thus, it was expected that emissions from the aircraft associated with commuter and foreign operators would represent a significant portion in the amount of total air pollutant emitted from aircraft main engines, although not all commuter and international flights were operated by commuter or foreign operators. The percentage of general aviation flights for the same time period was 5.7%, and these aircraft were not included in this study.

The number of LTO cycles for commuter and foreign operators were estimated from the published time schedule. The September 1999 issue was used for commuter operators and the October 1999 issue for foreign operators. These time schedules were used primarily for the dispersion calculation, more details of which are described in the subsequent chapter. The weekly number of LTO cycles for each aircraft type for each operator was taken from the time tables and multiplied by 52 weeks. An exception was made for Cape Air due to the expected strong seasonality. The weekly number of LTO cycles taken from the flight schedule publication was assumed to be valid for 26 weeks (summertime). The other 26 weeks (wintertime), the weekly number of LTO cycles was assumed to be 50% of the summertime.

Once the simple annual estimated number of LTO cycles were calculated, it was multiplied by the average ratio of total departures to scheduled departures at Logan International Airport in order to consider flight cancellations and non-scheduled flights. This information was retrieved from table 7 of the airport activity statistics, referred to above, and determined to be 0.98.

Appendix B lists the numbers of LTO cycles included in this study.

2.1.3 Airframe-Engine Matching

Once the fleet make-up was determined, the proper engine models were assigned to each aircraft included in the fleet make-up. The precise engine model information for each aircraft model and airline were taken primarily from *JP Airlines-Fleet International 1999/2000* published by Bucher & Co. Its fleet list includes aircraft model, engine model, manufacture date, delivery date, and configuration for each aircraft owned or ordered by 6,000 operators worldwide. Occasionally some small operators were missing in the list and the information was extracted from a secondary source, *Turbine-Engined Fleets of the World's Airlines* prepared by Aviation Data Service, Inc. It is not uncommon to find that different airplanes with the same exact aircraft model, owned by the same airlines, have different engines. In this case, the approximate percentage of the share of each engine model was determined. If the operator or the particular aircraft model for the operator was not found in either source, the most common engine for the aircraft model listed by the FAA was assigned.

2.1.4 Emission Factors Selection

The primary source used in this study was obtained from the Defense Evaluation and Research Agency of the United Kingdom's Ministry of Defense. The database includes the operating mode-specific emission index of hydrocarbons, carbon monoxide, and oxides of nitrogen and the fuel flow rate for approximately 300 jet engines. Detailed remarks are attached when multiple sets of measurements were found for a single engine model.

These multiple sets of measurements are usually due to a change in one of the engine components such as the combustor or fuel nozzle in order to achieve a reduced emission rate. For some of these engines, the dates of the beginning of the production for the low emission components are noted. In those cases, the appropriate sets of the measurement for the engine model was determined by comparing the beginning of the production dates to the manufacture dates of each aircraft. Two assumptions were made as this method was incorporated. First, the aircraft manufacture date and the engine manufactured date are the same. And second, the engine configuration does not change during the course of maintenance. The normal maintenance program does not change the configuration of the engines even when the life of the component is up and it is to be replaced. However, the configuration can be changed and the low emission components will be incorporated as a part of the service program. The effect of this service is assumed to be negligible since it is performed solely upon the aircraft operators discretion.

When the beginning of the production date for low emission devices was not available, the emission test dates of the engine were compared against the aircraft manufacture date and assumed that the low emission device was not available before the end of the testing date.

Two other databases were used in this study to obtain the emission rate for the engines not included in the primary source: The *FAA's Engine Emission Factor Database* and the system table of the FAA's Emissions and Dispersion Modeling System. With these three sources, the hydrocarbons, carbon monoxide, and oxides of nitrogen emission factors of most engine models were determined. When the emission factors of the exact model of the engine were not found, emission factors for similar engine models were substituted. The list of engines with substituted emission factors is included in Appendix E.

The measurements for sulfur oxides emissions from aircraft engines were rarely available. The emission index provided by the EPA were based on the national average sulfur content of aviation fuels, 0.05% by weight for commercial jet fuel, and 0.06% by weight for aviation gasoline. It is assumed that all sulfur in the fuel combines with oxygen during combustion to form sulfur dioxide. The sulfur oxides emission rates were calculated from the EPA's emission index and the fuel flow rate. Therefore, the sulfur oxides emission factors used in this study only depends on the aviation fuel type and is directly proportional to the operation-specific fuel flow rate.

The engine and mode specific measurement of the particulates, which form as a result of incomplete combustion, is extremely limited. Thus, particulate emissions from the aircraft engines are not included in this study. In general, the particulate emission index is higher at lower power rate than at high power rates since combustion efficiency improves at higher engine power. However, the particulate emission rates are highest during take-off and climb-out due to the higher fuel flow rates.

2.1.5 Annual Emissions Estimation

The basic equation to estimate the annual emissions of pollutant *i*, produced by all aircraft operating in the region of interest is

$$E_{Ti} = \sum_{j} (E_{ij}) \cdot (LTO_j) \qquad (2.3)$$

where

$$E_{ij} = \sum_{k} (T_{jk} \cdot 60) \cdot \left(\frac{FF_{jk}}{1000} \right) \cdot (EI_{ijk}) \cdot (N_j)$$

There are many different ways to sort the emissions depending on the purpose of the analysis. The above equation is based on the emission per LTO cycle of each aircraft. In this study, the emissions were sorted by the operating mode of all aircraft. Therefore the equation was modified as

$$E_{Ti} = \sum_{k} E_{ik} \qquad (2.4)$$

where

$$E_{ik} = \sum_{j} (T_{jk} \cdot 60) \cdot \left(\frac{FF_{jk}}{1000} \right) \cdot (EI_{ijk}) \cdot (N_j) \cdot (LTO_j)$$

2.2 Ground Support Equipment and Auxiliary Power Units

The activity of ground support equipment and auxiliary power units are closely related to the activity of aircraft. Upon arrival at the gate, the aircraft is met by ground support equipment to unload baggage and food carts, and to service the lavatory and cabin of the airplane. While the aircraft is parked at the gate, there are generators in operation to provide electricity and air. If the aircraft is scheduled to depart, ground support equipment is present to load baggage and food carts and to refuel. When the aircraft departs from the gate, an aircraft tug is used to push the aircraft from the gate and to the taxiway. Auxiliary power units are most often on-board generators that provide electrical power to the aircraft while its engines are shut down. Although the auxiliary power unit is a part of the aircraft, it is treated with the ground support equipment because of the similarity in operational characteristics.

The following four steps are performed to estimate the emissions from ground support equipment and auxiliary power units.

1) Determination of the set of ground support equipment and the auxiliary power unit for different aircraft categories by aircraft type, size and primary use.
2) Determination of the emission factors and operational times for ground support equipment and the auxiliary power unit per LTO cycle.
3) Determination of the number of LTO cycles for each set of ground support equipment and associated auxiliary power unit.
4) Estimation of annual emissions based on the number of LTO cycles, emission factors, and operational times per LTO cycle for ground support equipment and associated auxiliary power unit.

2.2.1 Ground Support Equipment and Auxiliary Power Unit Assignment

The types of ground support equipment and auxiliary power unit required for the particular aircraft depend on the aircraft type, size, and primary use. The aircraft included in this study were categorized in ten different groups, and the aircraft in each group were assigned to a set of standardized ground support equipment and auxiliary power units.

The standardized set of ground support equipment and auxiliary power unit and their operation times per LTO cycle were determined based on the default assignment found in EDMS. Some modifications were made in either the equipment types or operation times. The cabin service equipment was removed from all cargo flights and additional loading equipment was added. A shorter operating time per LTO cycle was used for baggage loading equipment assigned to smaller aircraft.

The complete list of aircraft in each of the 10 groups and the set of ground support equipment and auxiliary power unit and their operation times is attached in Appendix C.

2.2.2 Emission Factors Selection

The emission factors for ground support equipment and auxiliary power unit were taken from the EDMS database. These emission factors are derived from the document *Technical Data To support FAA's Advisory Circular On Reducing Emissions From Commercial Aviation.* The ground support equipment emissions are based on variables such as brake horse power, load factor, fuel type, and coolant type. The emission factors for ground support equipment included in this study are listed in Appendix F.

2.2.3 Annual Emissions Estimation

From the assignment, emission factors, and the number of LTO cycles, the emissions from ground support equipment and auxiliary power units were estimated by the following equations:

$$E_{Ti} = \sum_{q} \left(E_q\right) \cdot \left(LTO_q\right) \qquad (2.5)$$

where

$$E_{qi} = \sum_{p} \left(\frac{EF_p \cdot 1000}{60} \right) \cdot \left(T_p\right)$$

2.3 On-Road Vehicles

EDMS stores vehicular emission factors obtained from EPA's MOBILE5a and PART5 programs. These emission factors are valid for the default fleet mix of fleet years 1988 to 2010, at 14 different vehicle speeds, temperatures from 0 to 100 degrees Fahrenheit in 5 degree increments, and high and low altitudes.

The annual number of on-road vehicles were estimated from the daily number of on-road vehicles calculated for the dispersion modeling as described in the following chapter. This daily number of on-road vehicles is for weekdays, therefore the number of on-road vehicles for Saturdays and Sundays were estimated from the relative amount of flights on weekend days to the ones on Mondays determined from the published flight schedules. These factors were 0.78 for Saturdays, and 0.88 for Sundays.

For annual emission estimation, 16,339,815 vehicles with the 1998 default fleet mix was assumed to be at the average temperature of 52.3 Fahrenheit, and the average vehicle speed of 30 miles per hour.

2.4 Annual Emissions Estimation for 2010

The primary purpose of future annual emission estimations is to further investigate ways to minimize the environmental impact due to air pollutant emissions from airport mobile sources. While air traffic is expected to increase in the coming decade, the specifics of future airport operations are unknown. Therefore a hypothetical future scenario in 2010 was constructed to project the tendencies and characteristics of airport ground level air pollution. To do that, two sets of analysis were performed. The first assumed no increase in traffic, but an updated aircraft fleet. The second assumed an increase in traffic and an updated aircraft fleet.

2.4.1 Fleet Make-Up

An assumed fleet mix for the on-road vehicles for 2010 was already available in the EPA's MOBILE5a. As for the present time analysis, the default fleet mix was used for on-road vehicles.

The ground support equipment fleet make-up greatly depends on the aircraft fleet make-up itself, since different aircraft categories and use of aircraft require different sets of ground support equipment. It was assumed that the same set of ground support equipment would be required to service the same category and use of aircraft in the future as it is now. Further, it was assumed that the future ground support equipment would be powered by the same type of fuel.

The future aircraft fleet make-up is difficult to predict (there are always other possibilities besides the one used in this study) except for one condition; the retirement of all stage 2 aircraft by 2003. These aircraft include some Boeing 727, 737, DC-9, Dassault Falcon 20 as well as other aircraft models not relevant to this study. The carriers that operate stage 2 aircraft have a choice to either retire the stage 2 aircraft or upgrade them to stage 3 aircraft by changing the certified configuration of the engines. It seems that the carriers tend to retire stage 2 passenger aircraft while they are more likely to upgrade stage 2 freighters. For example, Boeing 727-200 series aircraft used for passenger transport is more likely to remain as stage 2 while a higher percentage of Boeing 727-200 freighters are categorized as stage 3. Also it was found that the percentage of stage 2 freighter LTOs is relatively small. For these reasons, none of the stage 2 freighters were replaced with newer aircraft. As a result, a maximum of less than 1% of flights in the future scenario in the study were associated with stage 2 aircraft.

For passenger transport, all stage 2 aircraft were replaced with newer aircraft. The replacement aircraft have two CFM56-3C-1 engines, and are essentially modeled after a newer version of the Boeing 737. There are two reasons to choose this aircraft as the replacement. First, the Boeing 737 has a similar seat capacity to the stage 2 passenger aircraft relevant to this study. Second, the Boeing 737 is popular among airlines; it is the best-selling commercial jetliner of all time.

2.4.2 Increase in Airport Activity

The increase in aircraft traffic in 2010 relative to the present day was assumed to be 10%. The Massachusetts Port Authority has published the Logan International Airport traffic forecast for 2010 using two different sets of assumptions for increases in passengers and airline operation patterns (i.e. low operations cases and high operations cases).

The low operations case translates to the assumption that the airlines will operate less commuter aircraft, therefore requiring less flights to accommodate a given number of passengers. The high operations case, on the other hand, reflects the greater use of small aircraft. Table 2-1 shows the forecast summary prepared by the Massachusetts Port Authority. The conditions at Logan International Airport when the forecast was made was reported to most closely resemble the 1999 low operations case in terms of the number of aircraft operations.

According to table 2-1, the assumed increase in aircraft operations in 2010 relative to 1999 ranges from 6.5% to 28.6% if 1999 operation is low. If 1999 operation is high, the changes in aircraft operations in 2010 varies from -1.6% to 18.8%.

The Federal Aviation Administration forecasts that the regional/commuter passenger traffic will continue to grow at a faster rate than their larger domestic counterparts. At the same time, the international passenger traffic is also forecast to

Year	Operations Level	No. of Passengers (Millions)	No. of Aircraft Operations
1999*	Low	29	510,000
	High	29	552,000
2010	Low	37.5	543,000
	High	37.5	608,000
	Low	45**	580,000
	High	45	656,000

* The forecast was published in February 1999, therefore 1999 values do not reflect the actual number of passengers and aircraft operations.

** A low operations forecast designed to accommodate 45 million passengers was not carried through the detailed analysis due to its similarity to the high operations case with 37.5 million passengers.

Table 2-1: Forecast for Logan International Airport prepared by Massachusetts Port Authority grow as fast as the regional/commuter passenger traffic. However, aircraft operation is not directly proportional to the increase in passenger traffic since the load factor cannot be assumed to be constant. The FAA expects total aviation activity at FAA facilities and their contract facilities to grow at a lower rate than either domestic, regional/commuter, or international passenger traffic. In an earlier forecast, the FAA estimated the annual growth rate of commercial travel activity at Logan International Airport to be 0.8% from 1997-1998 to 2009-2010, which corresponds to 9.16% in 11 years and 10% in 12 years.

Given all the information, the 10% increase in aircraft operation used in this study is a somewhat conservative figure. A conservative figure was used to avoid an over estimate of the air pollution impact from airport mobile sources in the future. Also it should be noted that in busy metropolitan airports, the facility may be closer to saturation level and dramatic increase in air traffic may not be achieved unless the facility undergoes expansion. As a result, the increase in traffic predicted by forecast may not be realistic if it purely relied on anticipated expected economic growth. Another point is that carriers may focus more on a nearby regional airport which has much less traffic but a reasonable access to the metropolitan area as an alternative to avoid congestion at the major airport. For example, regional airports in Worcester, Massachusetts, Providence, Rhode Island, and Manchester, New Hampshire can serve as alternatives for the Boston metropolitan area.

After considering the forecast and operational situation in major airports, a slightly conservative 10% increase in traffic seemed more justifiable than middle or sharp increases in traffic. The annual increase in on-road traffic was assumed to be directly proportional to the increase in air traffic, therefore a 10% increase was also applied.

3. Dispersion Modeling

The intent of dispersion modeling is to assess the air pollutant concentrations at or near the airport from airport mobile sources. These pollutant concentrations are calculated to determine whether emissions from the site result in unacceptably high air pollution levels downwind of the sources by comparison with the National Ambient Air Quality Standards (NAAQS) or other relevant air quality standards. In this study, the dispersion modeling was performed using the FAA's Emissions and Dispersion Modeling System (EDMS). This system is especially designed for air quality assessment at airports and air bases. The following paragraphs provide a brief overview of EDMS.

The basic Gaussian equation for the steady-state dispersion of pollutants from a continuous point source is given below:

$$C(x,y,z,H)=\frac{Q}{2\pi\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)\right]^2\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \quad (3.1)$$

The point sources are used to model the activity at the gates and stationary sources. The gate activity includes the ground support equipment and auxiliary power unit of the aircraft. The stationary sources include the airport power plants and training fire sessions.

Three other sources are used to model the airport related dispersion. The line sources are used to estimate the dispersion from aircraft taxiing, aircraft queuing, and on-road vehicle operations. These line sources are considered as the uniformly distributed set of point sources along the length of the lines. The dispersion from the aircraft on the runway is modeled with an accelerating line source. For the airport parking lots, which generate emissions due to on-road vehicle operations and vehicle idling, the area sources are used. These area sources are considered as a grid of evenly spaced point sources.

EDMS uses the following systems to incorporate several different types of emission sources: the PAL2 point source module for all point sources, the PAL2 slant line source module for the runway, the CALINE3 for aircraft taxiing, aircraft queuing and motor vehicles on roadways, and the PAL2 area source module for parking lots.

3.1 Applications to Logan International Airport

The dispersion calculation for Logan International Airport was performed by constructing the airport activity model for a typical day operation, which was defined as a scheduled weekday operation at the airport.

3.1.1 Airport Modeling

An accurate representation of the airport is important in order to determine the location and movement of the emission sources. The relevant components of the airport were modeled as accurate as possible based on the information available from a published flight guide and a few other sources. Figure 3-1 shows the modeled airport used in this study. The model uses a Cartesian coordinate system with the positive x-direction pointing true east, and positive y-direction pointing true north. The intersection of runway 9 and runway 4R was randomly selected as the origin of the coordinate system. All coordinates in this study have the measurement unit in feet. The modeled airport has some simplifications and substitutions due to either the limited flexibility of EDMS or the limited information available at the time of the study. Each modeled airport component is described in the following paragraphs.

Runways

All five existing runways at Logan International Airport were entered in the system, only three of which were used in the dispersion calculation. The runways are named based on their magnetic orientation. For example, the runway pointing to magnetic north is called "runway 36", east is "runway 9" and so on. Therefore each runway strip has two names depending on the direction. The Cartesian coordinate system used in EDMS is defined such that true east is in the positive x-direction, and true north is in the positive y-direction. The difference between true north and magnetic north in Boston is approximately 13 degrees. As a result, runway 9 is pointing 77 degrees from north while its magnetic orientation is pointing 93 degrees from north.

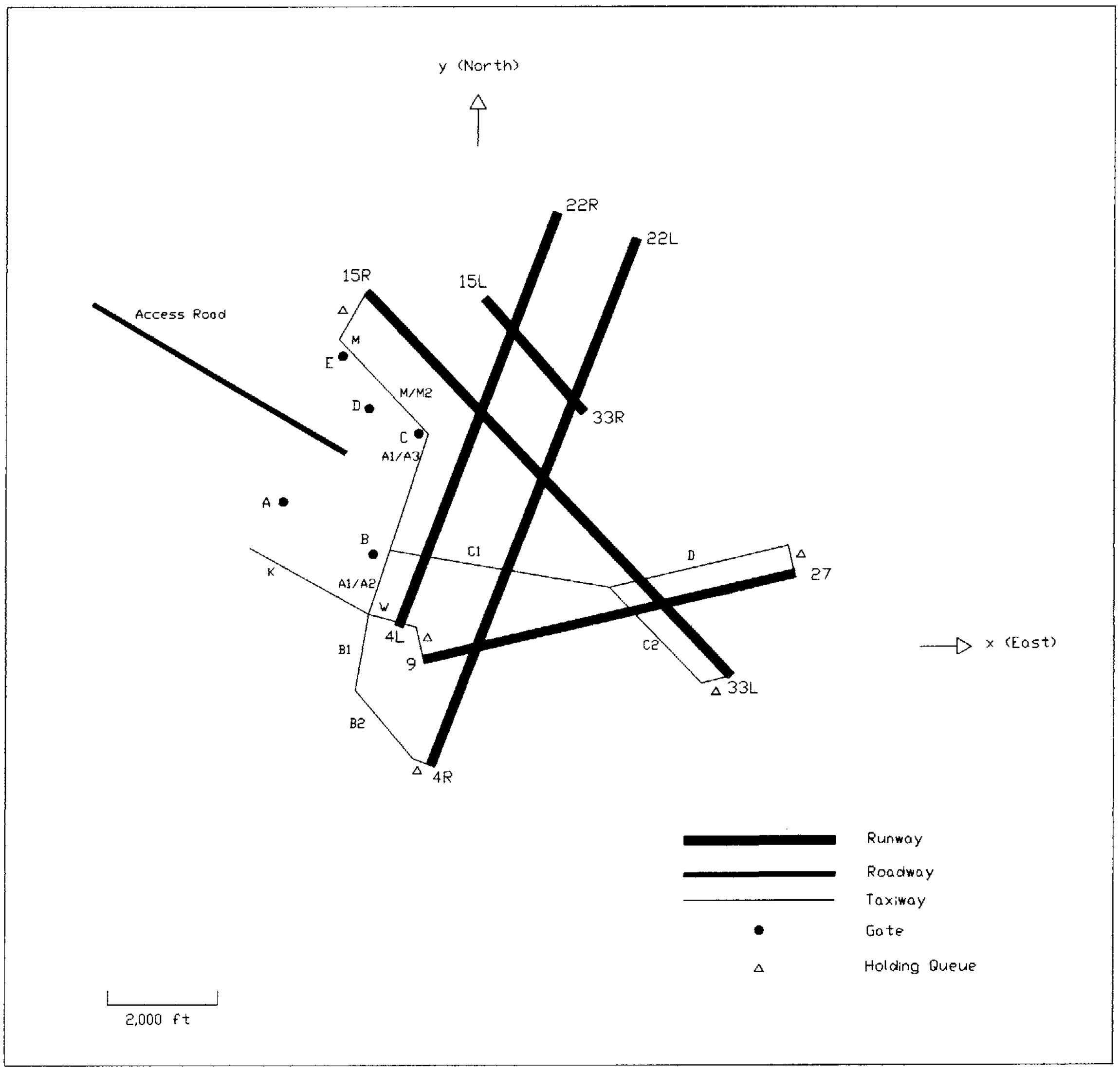


Figure 3-1: Modeled Logan International Airport

Taxiways

There are many taxiways at Logan International Airport. Only the ones relevant to this study were entered. Taxiways are named with a letter or a letter with a number. Although the taxiway names used in the system have the same format and are based on the real taxiway names, they may not be exactly the same. The taxiways in the system are all in straight lines and some overlap each other. For example, taxiway M2 is a portion of taxiway M. The overlaps were made in order to add flexibility and accuracy to aircraft movement. The taxi time for each taxiway was assumed to be proportional to the length of the taxiway. The coordinate of two endpoints of each of the taxiways and their corresponding taxi times are shown in table 3-1.

Taxiway	End 1 (x, y)	End 2 (x, y)	Taxi time (minutes)
A1	-885, 3832	-1957, 594	6.8
A2	-1582, 1741	-1957, 594	2.4
A3	-885, 3832	-1582, 1741	4.4
B1	-1957, 594	-2192, -769	2.8
B2	-2192, -769	-1146, -1999	3.2
C1	-1582, 1741	2384, 1077	8.0
C2	2384, 1077	4054, -644	4.8
D	2384, 1077	5623, 1825	6.6
K	-4095, 1775	-1957, 594	4.9
M	-2505, 5527	-885, 3832	3.7
M2	-1916, 4911	-885, 3832	3.0
W	-1957, 594	-1093, 363	1.8

Table 3-1: Taxiway coordinates (in feet) and taxi time for each taxiway

Holding Queue

The holding queue is a spatially defined line source in the EDMS coordinate system for the purpose of calculating dispersion due to aircraft waiting to enter the runway. Each active runway used in the study has a holding queue. In order to include the dispersion, EDMS requires the average time the aircraft spends in the queue as well as the coordinate of the beginning of the queue (the end being the beginning of the runway). Both the length of the queue and the average time spent in the queue depend on the activity level of the airport at any given time. EDMS allows for the specification of peak values and hourly operational profiles of length and average time to incorporate the activity level. In this study, the length of the queue was fixed and only the average time spent in the queue was varied in proportion to the sum of the number of take-offs and landings for each hour. The peak value of average time was estimated to be seven minutes. This is the total waiting time, which is the sum of waiting times prior to entering the queue, in the queue, and during the "hold position" on the runway at the peak hour. Random monitoring of airport radio communications during morning rush hour showed typical hold position time was two to three minutes. It was assumed that when an aircraft arrived at the queue, it would be third to take-off.

Gates

A gate is a physical point of arrival and departure for the aircraft. It is almost impossible to include all gates at a major airport and assign each flight to a specific gate. For this reason, only one gate for each of the five terminals at Logan International Airport was created in the system. The exact coordinates of the gates were chosen so that the location in the system would be at or near the center of all the gates at each terminal. The gate location is most reasonable for terminal E and least reasonable for terminal B due to the building shapes. The locations of the gates are shown in table 3-2.

Roadways

Logan International Airport has loop shaped roadways along the terminals and near the subway station. The roadway entered in the system was significantly simplified compared to the other components of the airport for the following reasons: 1) EDMS only allows straight-line roadways, and 2) the parameters required for each roadway were difficult to obtain or estimate if a multiple-roadway system was to be employed.

The modeled roadway is one mile long and has one endpoint at (-2384, 3486) and the other at (-6937, 6161).

Gate	Location (x, y)
A	-3500, 2615
B	-1878, 1672
C	-1061, 3836
D	-1955, 4287
E	-2436, 5229

Table 3-2: Gate coordinates in feet

3.1.2 Meteorological Data

The meteorological data is important as the dispersion calculation is highly dependent on the meteorological conditions. The required meteorological elements for the dispersion calculation are mixing height, temperature, wind speed, wind direction and Pasquill-Gifford Stability Classification, or the PG stability class. The mixing height is assumed to be subject to little change and is input once as a constant. The other four parameters can be specified as detailed on an hourly basis.

The actual 1999 surface weather observation data at Logan International Airport was obtained from the National Oceanic and Atmospheric Administration (NOAA). EDMS has the capability of importing weather data from the NOAA's TD-1440 files and creating a refined weather file for the dispersion calculations. EDMS reads the ceiling height, sky condition, wind direction, wind speed, dry bulb temperature along with the observation station number, year, month, day, and the hour of the observation from TD-1440 files. The PG stability class for each hour is calculated based on the weather data. Unfortunately TD-1440 files are no longer available for the year 2000 issue, according to the NOAA. However, the surface observation data is now available with TD 9956 files.

A FORTRAN program was written to read the weather data from the TD 9956 file and reformat it to the TD-1440 files.

3.1.3 Emission Sources

Aircraft

The typical-day aircraft operation at Logan International Airport for September 1999 was determined from a published flight schedule, the *Official Airline Guide* (OAG). OAG's North America September 1999 issue covers all scheduled passenger flights which have both origin and destination in the United States and Canada regardless of the operator's nationality. The international flight information was retrieved from OAG's worldwide October 1999 issue. A number of flights had schedule changes during the month and some seasonal flights were discontinued. Only flights with schedules effective for more than 15 days during the month were considered. The total of 658 take-offs, operated by more than 30 carriers, were included in the typical-day operation. Figure 3-2 shows the number of hourly departures for each gate. The detailed hourly operational profiles, which were based on the Monday schedule are included in Appendix G.

The following types of flights are not included in the typical-day aircraft operation: charter flights, cargo flights other than DHL Airways, general aviation, and helicopters. The cargo flights operated by DHL Airways were added because its flight schedule was provided by the operator.

The engine model for each flight was determined from the aircraft operator and the aircraft model similar to the way it was determined for emission inventory. However, only the most common engine type for the aircraft model owned by the operator was used for the dispersion modeling.

At this time, the approved algorithms for the modes of approach and climb out are not available. EDMS only calculates the dispersion for aircraft in the modes of taxi, idle, and take-off. The landing information at the airport was used only to determine the operational profiles for on-road vehicles and the holding queue.

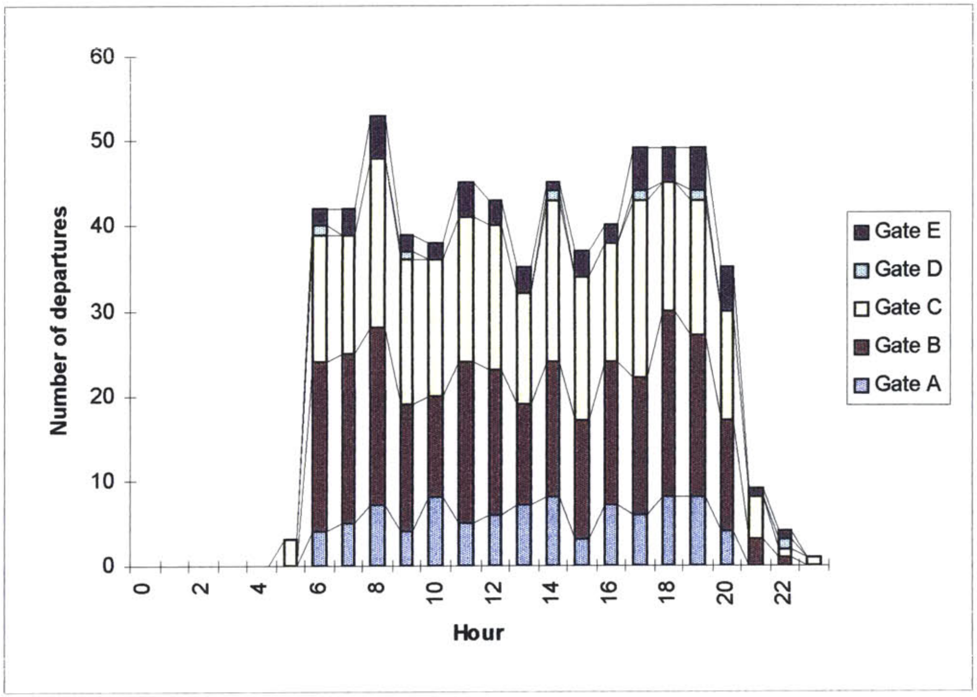


Figure 3-2: Number of hourly departures by gates

Ground Support Equipment and Auxiliary Power Unit

The ground support equipment and auxiliary power unit assignment for each aircraft was performed in the same manner as for the emission inventory.

On-Road Vehicles

Although the on-road vehicle activity is easily assumed to be related to the aircraft activity level or the number of passengers in some way, the exact relationship is unknown. Not all flights have the same number of passengers, nor do all passengers use on-road vehicles to shuttle to and from the airport, and some passengers are transient. In order to establish some means of activity level of on-road vehicles, the following assumptions were made:

1) Each departing and arriving flight requires the same number of on-road vehicles to provide ground transportation to the passengers. Therefore, the number of on-road vehicles is directly proportional to the number of take-offs and landings.

2) All departing passengers arrive at the airport 60 minutes prior to their flights.

3) All arriving passengers leave the airport 30 minutes after their aircraft arrival at the gates.

4) There are 3,600 vehicles passing through a point on the airport roadway during peak hour.

Once the assumptions were made, the relative magnitude of the number of on-road vehicles for each hour was determined from the aircraft departure and arrival times. Table 3-3 shows the operational profile (as 1.0 being the peak hour) for the on-road vehicles and total aircraft operations (both take-off and landing).

Hour	Operational profile		Hour	Operational profile	
A.M.	On-road vehicle	Aircraft	P.M.	On-road vehicle	Aircraft
0:00-0:59	0.07	0.07	0:00-0:59	0.73	0.78
1:00-1:59	0.07	0.03	1:00-1:59	0.82	0.75
2:00-2:59	0.07	0.00	2:00-2:59	0.80	0.87
3:00-3:59	0.00	0.00	3:00-3:59	0.74	0.73
4:00-4:59	0.03	0.00	4:00-4:59	0.91	0.88
5:00-5:59	0.41	0.03	5:00-5:59	1.00	0.93
6:00-6:59	0.45	0.52	6:00-6:59	0.94	1.00
7:00-7:59	0.68	0.65	7:00-7:59	0.8	0.88
8:00-8:59	0.68	0.89	8:00-8:59	0.44	0.77
9:00-9:59	0.75	0.76	9:00-9:59	0.47	0.47
10:00-10:59	0.84	0.79	10:00-10:59	0.37	0.32
11:00-11:59	0.89	0.92	11:00-11:59	0.17	0.11

Table 3-3: Aircraft and on-road vehicle operational profiles

3.1.4 Receptor Grid

The EPA suggests that the receptors should be located at: 1) places of expected maximum concentrations; 2) places where the general public has access over the time periods specified by the NAAQS; and 3) places where reasonableness is assumed. Some examples of unreasonable receptor sites include the median strips of roadways, on or close to an aircraft runway or taxiway, and tunnel approaches. An example of the reasonable places is a sidewalk to which the general public has access on a continuous basis.

Two dimensional grid receptors, as opposed to the discrete receptors, were generated to cover the entire airport and the immediate surroundings in order to visualize the motion of the air pollutants. The receptors were uniformly distributed in both x and y directions as shown in figure 3-3. The spacing between the two adjacent receptors is 1,000 feet. The height of the receptors was uniformly set at 5.9 feet, which is the recommended breathing height of the general public.

3.2 Model Days for Dispersion Calculation

As stated previously, the dispersion calculation is highly dependent on the meteorological conditions at the location in question. Moreover, the active runways, which dictate which taxiways to use, are determined by the wind direction and wind speed at the airport. This is because avoiding tail winds and minimizing cross winds is necessary to ensure safety. Therefore, the meteorological conditions not only affect the dispersion, but also determine the locations of the emission sources (i.e. aircraft). Logan International Airport experiences various meteorological configurations during the course of the year. This study focused on the northeast wind conditions because it would locate some terminals and downtown Boston areas, which are downwind from the emission sources.

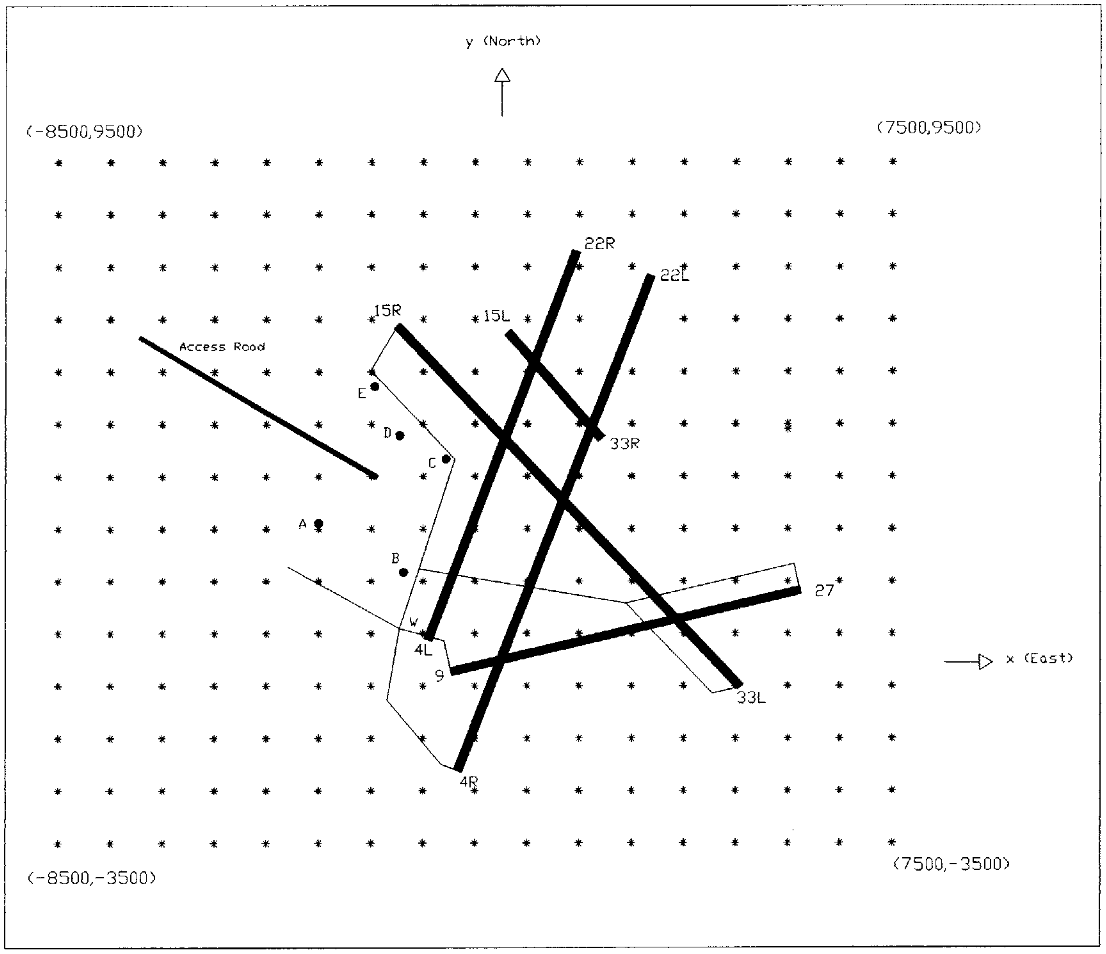


Figure 3-3: Two dimensional receptor grid, coordinates in feet (height = 5.9 ft)

3.2.1 Meteorological Conditions

Since the aircraft activity was retrieved from schedules for September 1999, the model day was sought from the same month. Upon reviewing the surface observation data, it was found that the wind direction was relatively consistent from the northeast on September 5, 1999 for a period of 24 hours and therefore it was chosen as the model day.

There were a total of five dispersion calculations performed in this study. Four of which were based on the model day. And one of which was based on the wind directions of an alternative-day, while all other meteorological conditions were based on the model day.

The actual meteorological conditions were used for the first dispersion calculation. The hourly wind directions are bounded between 40 and 90 degrees from north for 24 hours, while the hourly wind speeds split into two regions: the low-wind speed region for the evening and early morning, and the high-wind speed region for the late morning and afternoon as shown in figure 3-4.

Based on the wind speed profile, two other dispersion calculations were performed: low-wind speed dispersion and high-wind speed dispersion. For low-wind speed dispersion, the high wind speed values were artificially lowered by subtracting 4 m/s from the actual wind speed and the PG stability class was modified to fit the new meteorological conditions. For the high-wind speed dispersion, the opposite modification was applied. The low wind speed values were artificially increased by adding 4 m/s to the actual wind speed. The PG stability class was also modified. There were no modifications for wind directions.

The fourth dispersion calculation was performed using the actual meteorological conditions. However, the ground support equipment, except for aircraft tugs, was excluded so that the contributions from ground support equipment to the local air quality could be determined. The aircraft tugs, which seemed modeled realistically, were included in the calculation because achieving higher operational efficiency was not assumed probable.

The last dispersion calculation was based on the alternative wind directions observed on September 18, 1999. The hourly wind directions were bounded between 280 and 340 degrees from north for 24 hours. Only the wind directions were altered in this dispersion calculation. Other variables such as wind speed, PG stability class, and temperature were kept the same as the model day.

3.2.2 Runway and Taxiway Assignment

The active runways for the four dispersion calculations based on the model day (northeast wind setting) are runway 9 and runway 4R. There was no systematic way to determine the specific runway assignment for each flight. At the same time assigning only one runway for all flights is not realistic. For these reasons, it was assumed that all

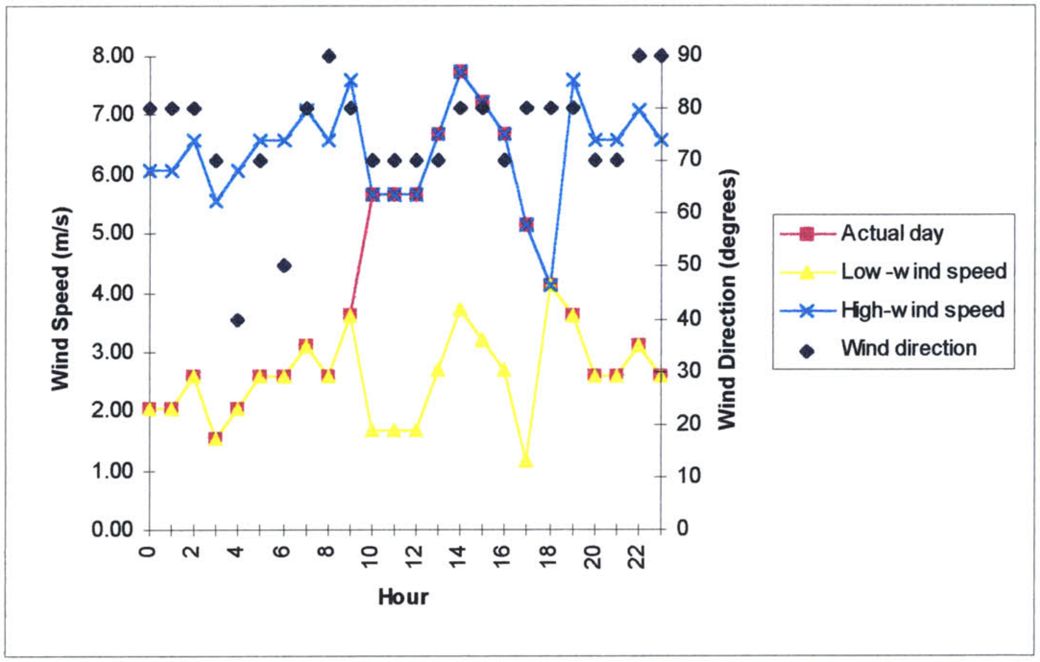


Figure 3-4: Wind conditions on the actual model day, low-wind speed and high-wind speed modified days.

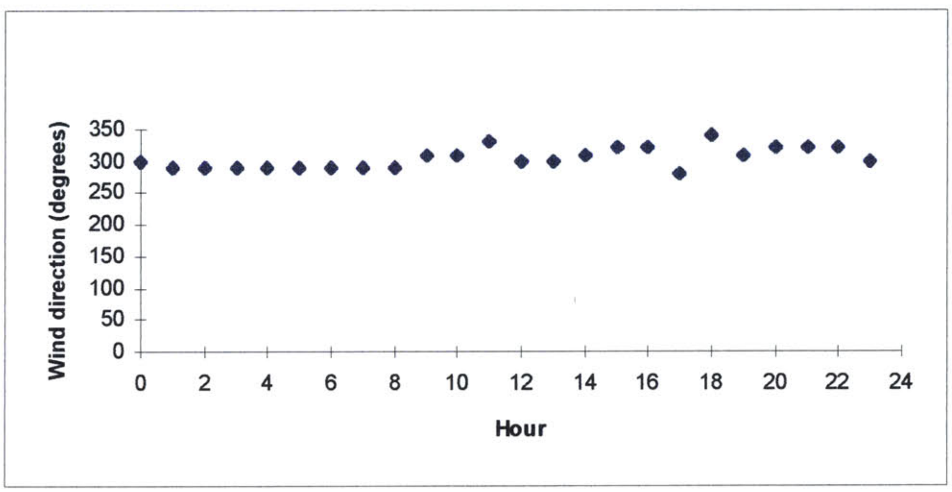


Figure 3-5: Alternative wind directions.

heavy aircraft were assigned to the longer runway (runway 4R) and the rest of the aircraft were assigned to runway 9. The heavy aircraft assigned to runway 4R include all series of Boeing 747, 767, 777, DC-10, and MD-11, Airbus A340, and Lockheed Martin L-1011.

The active runways for the alternative wind direction dispersion calculation (northwest wind setting) are runway 27 and 33L. Runway 33L is the longer of the two, and the same principle was used, as above, to determine the specific runway assignment to the aircraft.

The taxiway assignments were made according to the gates and runways assigned to the aircraft. The gate assignment was made purely by the aircraft operators as listed in Appendix D. Although some substitutions and assumptions were made, for the most part, the gate assignments reflect the use of terminals at Logan International Airport.

EDMS only allows assignment of up to three taxiways per aircraft. When more than three taxiways were needed, two taxiways near the gates were replaced with a single taxiway connecting the beginning of the first taxiway and the end of the second taxiway with a straight line. The taxi time for the substitute taxiway was determined by adding the two taxi times for the original taxiways. Therefore the aircraft taxi speed for the substitute taxiway is not consistent with the original value. Figure 3-6 shows all substitute taxiways used in this study and table 3-5 shows the taxiway assignment for all gate and active runway combinations.

Substitute Taxiway	Replaced Taxiways	Relevant Gate
AB	A1, B1	D,E
K-A2	K, -A2 *	A
M2A3	M3, A3	D
MA3	M, A3	E

*Negative sign indicates the opposite direction

Table 3-4: Substitute and replaced taxiways

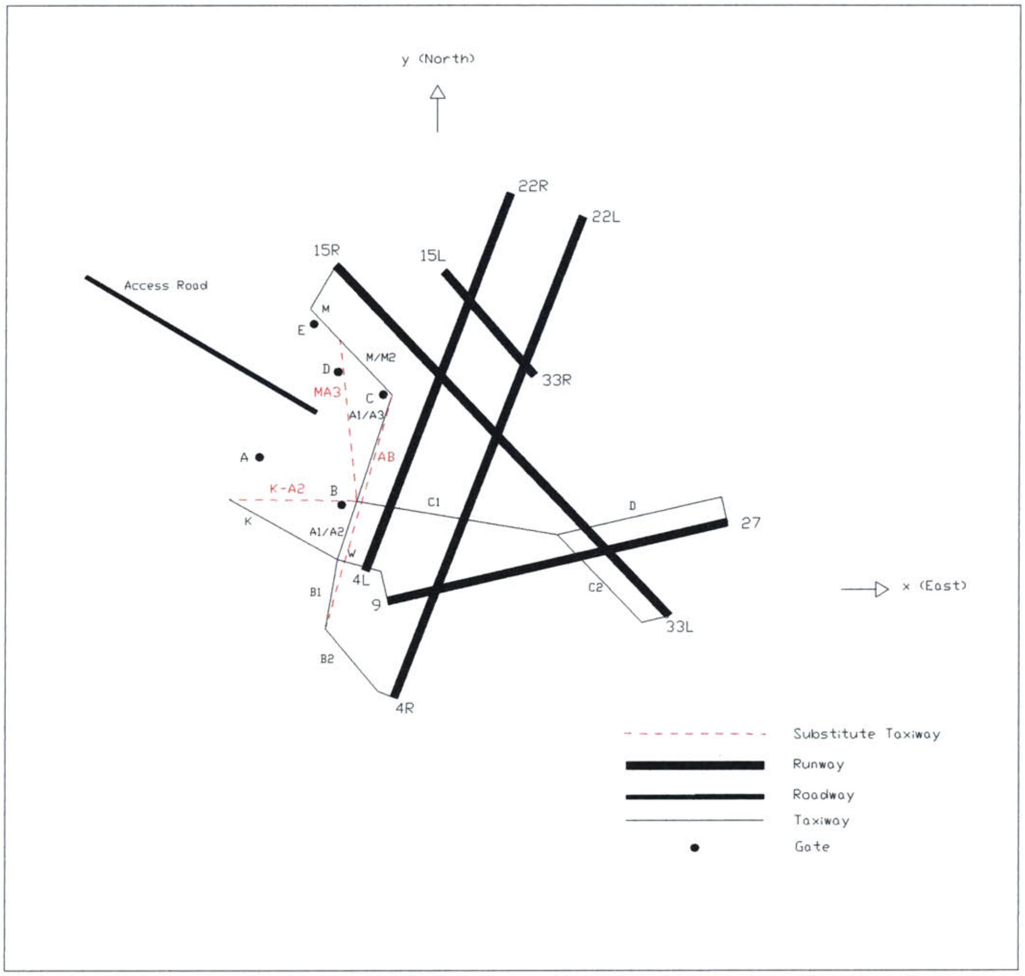


Figure 3-6: Substitute taxiways

3.3 Dispersion Calculation for 2010

A dispersion calculation was performed for the future scenario with a 10% increase in traffic. Airport configurations and gate assignments were same as the recent-year study. All assumptions made on fleet make-up and increases in traffic used to estimate annual air pollutant emissions in the future scenario were also used for the dispersion analysis. It was further assumed that the hourly operational profile for each aircraft model at each gate would be the same in the future. The number of flights during peak hours for each aircraft was calculated backwards from the annual number of LTOs and the hourly operational profile. As a result, the number of flights during the peak hour is generally no longer an integer. There were two reasons for this method of calculation. First, there is no simple way to predict future airline schedules. And second, the comparison to the present day situation would be much more direct if hourly operation remained the same. A counterargument to this method might be that the number of flights during airport peak hours, which may have already been at maximum capacity, would be increased accordingly, thus it does not model the future situation realistically.

The actual meteorological conditions on September 5, 1999 were used for the dispersion analysis for the future scenario in order to isolate the impact of increases in traffic and changes in aircraft and vehicular fleets to air quality.

Gate	Runway	Taxiways	Gate	Runway	Taxiways
A	15R	N/A	D	15R	N/A
	4R	K → B1 → B2		4R	M2 → AB → B2
	9	K → W		9	M2 → A1 → W
	27	K-A2 → C1 → D		27	M2A3 → C1 → D
	33L	K-A2 → C1 → C2		33L	M2A3 → C1 → C2
B	15R	-A3* → -M*	E	15R	NONE
	4R	A2 → B1 → B2		4R	M → AB → B2
	9	A2 → W		9	M → A1 → W
	27	C1 → D		27	MA3 → C1 → D
	33L	C1 → C2		33L	MA3 → C1 → C2
C	15R	-M*			
	4R	A1 → B1 → B2			
	9	A1 → W			
	27	A3 → C1 → D			
	33L	A3 → C1 → C2			

*Negative sign indicates the opposite direction.

Table 3-5: Taxiway assignments

3.4 Validation

3.4.1 Validation Description

In order to get a sense of accuracy in the model, a set of dispersion calculations was compared to the observed air quality near Logan International Airport. The existing monitoring site is located right outside the Northwest boundary of the airport, and the corrected air quality data for the month of September 1999 was obtained from the Commonwealth of Massachusetts' Executive Office of Environmental Affairs.

If the wind direction is Southeast, the emissions from the airport are expected to affect the air quality recorded at the monitoring site. During the month of September 1999, the Southeast wind was not recorded for 24-hours consecutively. However, on September 30, 1999, the wind direction was ideal for comparison from midnight to noon. Since it was the longest time frame with the ideal wind direction, the comparison between observed and predicted air quality levels was made during these hours. The hourly wind conditions on September 30, 1999 are shown in figure 3-7.

Airport Operations

Under the Southeast wind conditions, it is unlikely that runway 4R is used as an active runway, while runway 9 can be active depending on the wind speed. For the validation calculation, runway 9 was kept active and runway 4R was replaced with runway 15R.

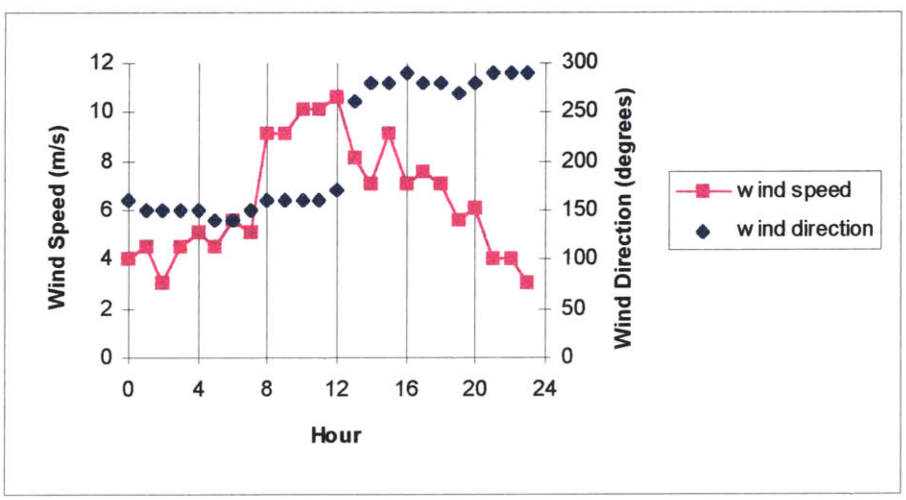


Figure 3-7: Hourly wind conditions on September 30, 1999

Since runway 15R is longer than runway 9, there was no change in runway or taxiway assignments for the aircraft assigned to runway 9 on the September 5, 1999 model day. All the aircraft assigned to runway 4R on the model day were assigned to runway 15R for the validation calculation. The taxiway assignments for those aircraft are summarized in table 3-5. All other operational conditions, such as gate and ground support equipment assignments and hourly operational profiles, were kept the same as the model day.

Monitor Location and Receptor Grid

The coordinates of the monitoring location in the model was determined approximately as (-5000, 7500). The average of calculated air pollutant levels at the two closest grid points, (-4500, 7500) and (-5500, 7500), was used as the predicted value at the monitoring site and compared to the observation. The height of the receptor grid was set at 13.1 feet, which corresponds to the probe height at the monitoring site.

Data Comparison

All observed data obtained for this study are expressed in parts per million. All predicted values are in micrograms per cubic meter. Except for the oxides of nitrogen, these values were converted to parts per million. All sulfur oxides were assumed to be in the form of sulfur dioxide.

For oxides of nitrogen, the observed data in parts per million for nitric oxide and nitrogen dioxide were converted to values in micrograms per cubic meter and added to determine the total observed oxides of nitrogen. This method was used since the predicted values do not include any information on partitioning, and an assumption that all oxides of nitrogen in the form of nitrogen dioxide may introduce an error. No similar calculation was made for sulfur oxides since sulfur dioxide is the only relevant species measured at the monitoring site.

Highway Emissions

The monitoring site is in close proximity to the airport making it an ideal location for data comparison, except that there is a highway between the airport and monitoring site.

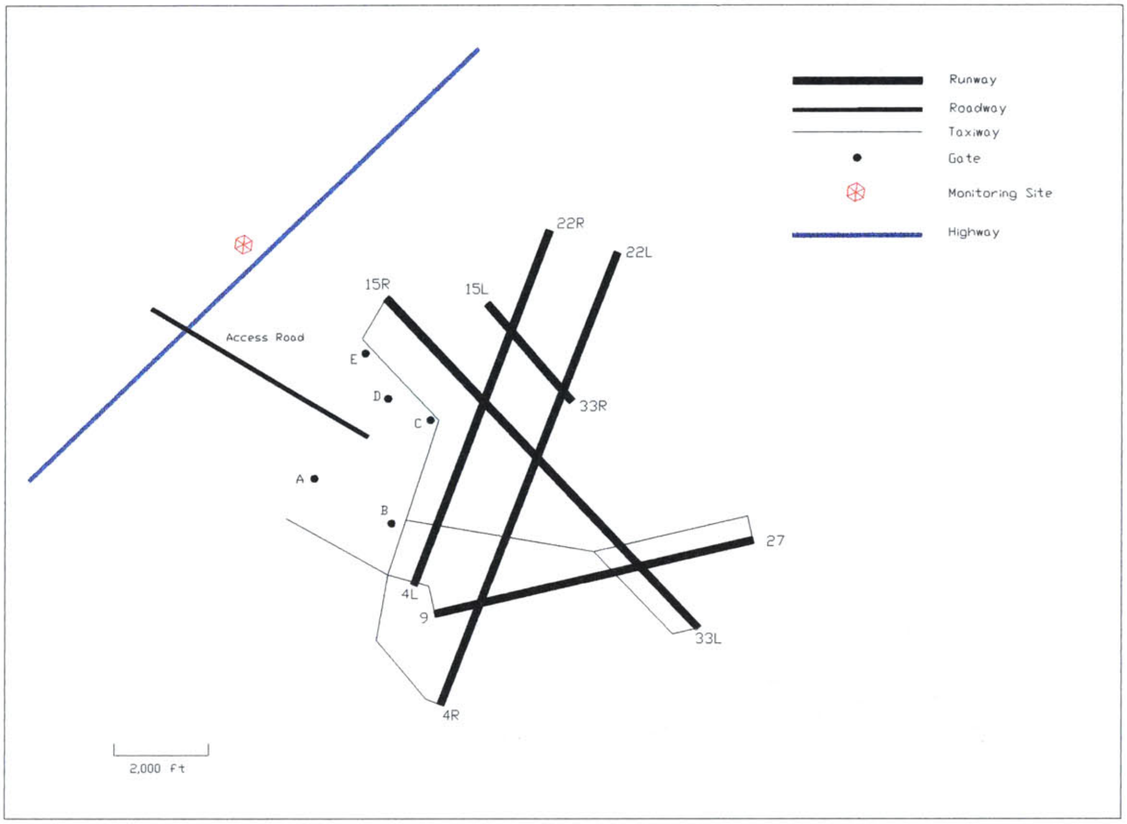


Figure 3-8: Monitoring site and highway

The monitoring site is directly downwind of the highway, as shown in figure 3-8, and it was expected that the highway emissions would affect the observed air quality at the site. Therefore, two sets of validation calculations were performed; one with the highway, and one without the highway.

The highway traffic was assumed to have the same hourly operational profile as the airport access road except for the morning and evening rush hours. The amount of traffic between 6 A.M. and 8:59 A.M. and from 4 P.M. and 6:59 P.M. was assumed to be at the peak value of 7,200 vehicles per hours. The 1999 default fleet mix and the average vehicle speed of 45 miles per hour were assumed for 24 hours.

3.4.2 Validation Results

Figures 3-9 (a) ~ (c) show the observed and predicted air pollutant levels for oxides of nitrogen, carbon monoxide, and sulfur dioxide. The predicted values after 1 P.M. are negligible due to the change in wind directions. The predicted oxides of nitrogen concentrations at 8 A.M. and 3 P.M. are shown in figure 3-10 (a) and (b). Observed data for carbon monoxide and sulfur dioxide were not available during some hours. The

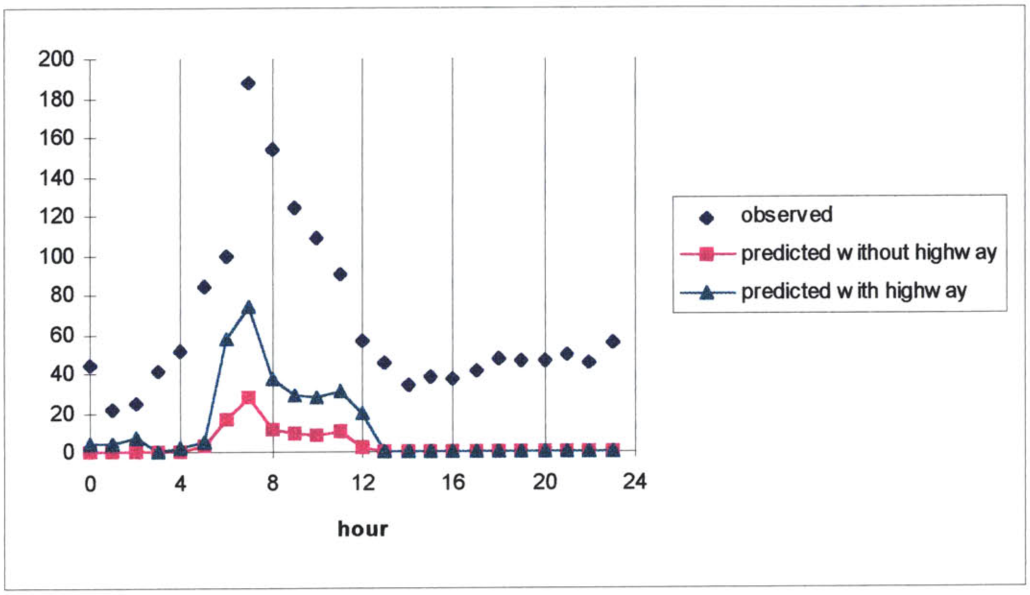


Figure 3-9 (a): Observed and predicted NO_X concentrations at monitoring site on September 30, 1999, in micrograms per cubic meter

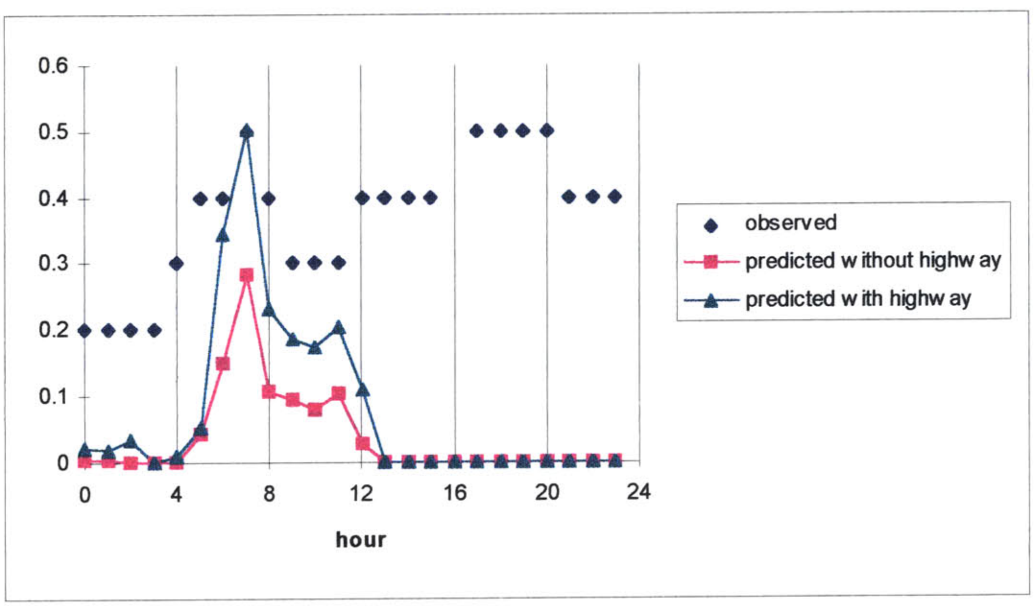


Figure 3-9 (b): Observed and predicted CO concentrations at monitoring site on September 30, 1999, in parts per million

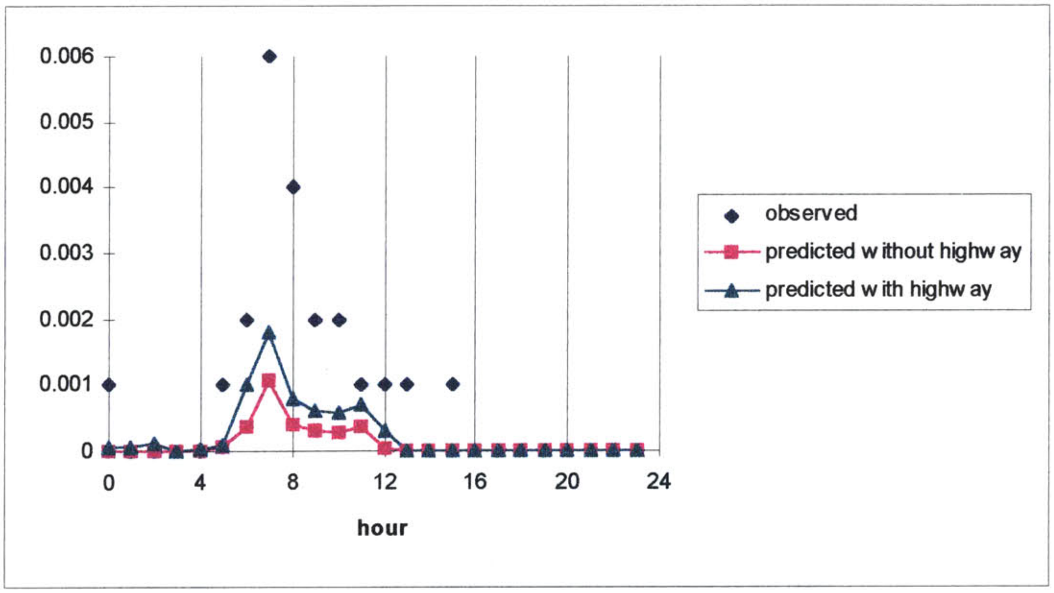


Figure 3-9 (c): Observed and predicted SO_2 concentrations at monitoring site on September 30, 1999, in parts per million

predicted values are always lower than the observations, however, they capture the dynamics of the air quality levels fairly accurately.

The predictions do not include the background values, which explains the difference in part. The observations during the hours with Northeast wind directions in the same month suggest that the background values are on the same order of magnitude as the difference between observations and predictions without highway emissions at least for oxides of nitrogen. These observations are less likely to be influenced by city emissions since the ocean is in an upwind position of the monitoring site. However, they are assumed to be somewhat affected by the highway because of its close proximity to the monitoring site and its orientation.

The difference between observations and predictions with highway emissions is smaller than the difference with predictions without highway emissions especially for carbon monoxide. This supports the explanation about the difference, described above, since the highway emissions were treated as background when they were not included in the predictions. The background values without highway emissions are difficult to estimate because, once again, the monitoring site is very close to the highway. If the wind direction is Northwest, it is likely that the observations are affected by the city emissions.

From these comparisons, it was concluded that the results from the dispersion calculations are qualitatively accurate, and most likely reflect the contributions from airport mobile sources to air quality. Some limitations and unrealistic modeling inside the airport are discussed in the following chapter.

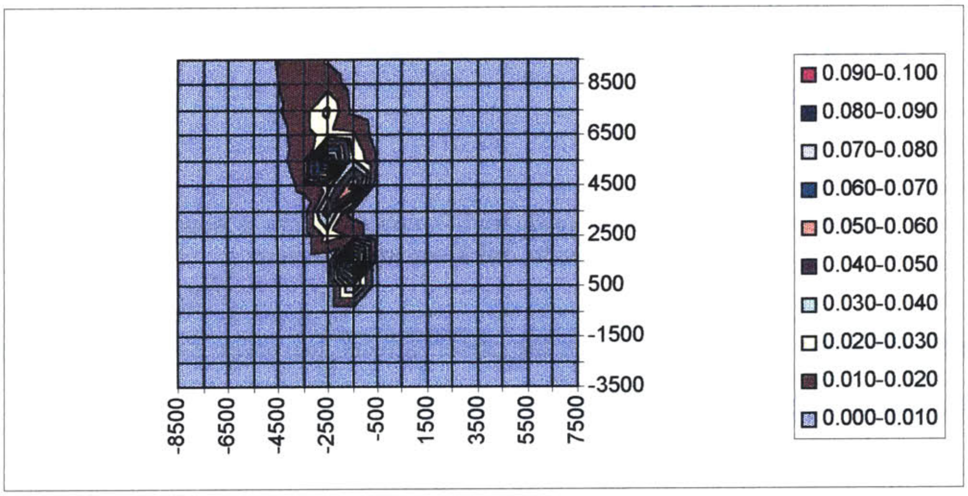


Figure 3-10 (a): Predicted NO_X concentrations at 8 A.M[1]

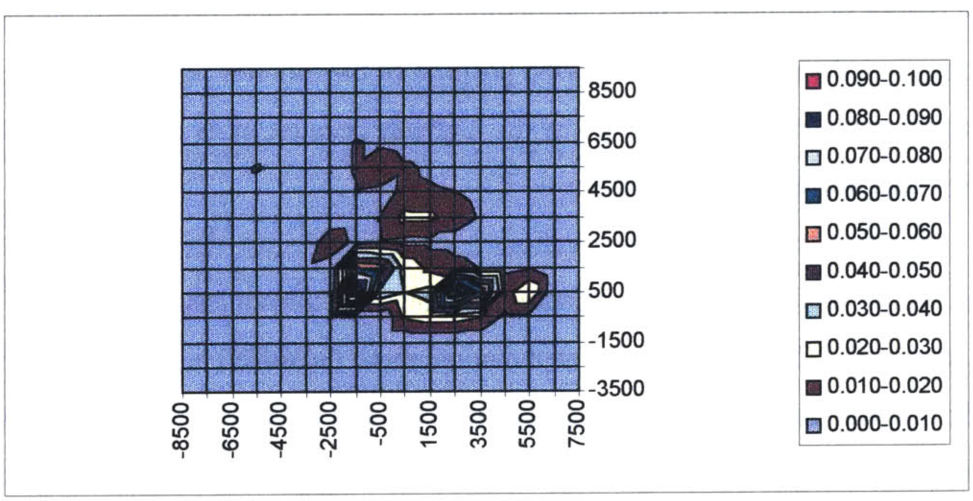


Figure 3-10 (b): Predicted NO_X concentrations at 7 P.M[1].

[1] Peak concentrations are greater than 0.1 PPM

4. Result

4.1 Annual Emissions Estimation

4.1.1 Recent-Year Evaluation

Table 4-1 summarizes the estimated annual emissions from all sources included in the study. The emissions from auxiliary power units were included in the aircraft emissions. The percentages of auxiliary power units emissions to the total aircraft emissions were 0.5% for hydrocarbons, 2.7% for carbon monoxide, and 4.0% for oxides of nitrogen. These percentages are rough values as the auxiliary power units were not assigned to the individual aircraft, but to the groups of aircraft similar in category. The total number of LTO cycles included in this study was 214,208.

Except for carbon monoxide emissions, the aircraft main engines are responsible for the majority of air pollutant emissions at the airport. For carbon monoxide, emissions from ground support equipment is as significant as from aircraft main engines.
The emissions from vehicular sources, as shown below, is an underestimate of the real value since the intra-airport roadways were simplified and no airport parking lot was included in the study.

Emission Source Category	**HC**	**CO**	**NO_X**	**SO_X**	**PM10**
Aircraft	1381.61	5084.04	1901.08	108.96	N/A
Ground Support Equipment	103.31	4617.72	295.06	10.57	12.40
On-Road Vehicles	41.07	390.49	47.01	2.04	2.14
Total	1525.98	10092.24	2243.15	121.57	14.54

Table 4-1: Estimated annual emissions from airport mobile sources, in tons of pollutant

It was found that the emissions related to non-jet flights were fairly significant for hydrocarbons and carbon monoxide. While the number of LTO cycles for non-jet flights

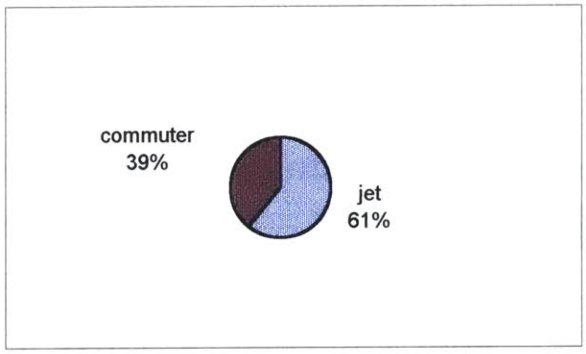
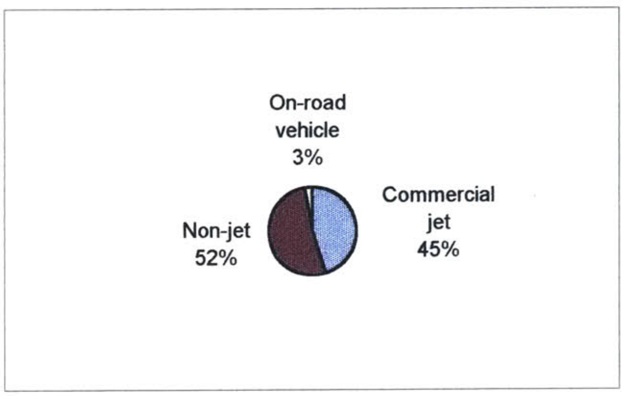
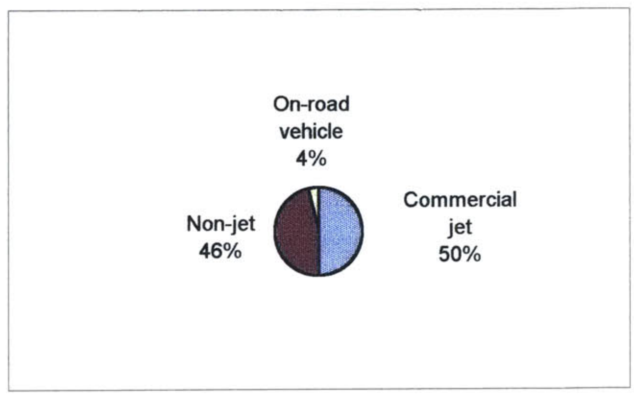


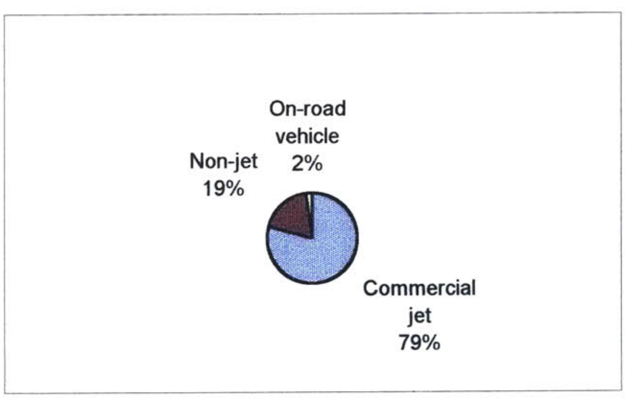
Figure 4-1: Percentage of LTO cycles



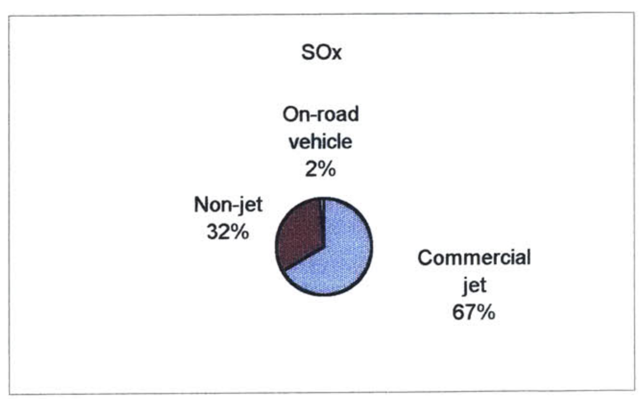
(a) Hydrocarbon emissions



(b) Carbon monoxide emissions



(c) Oxides of nitrogen emissions



(d) Sulfur oxides emissions

Figure 4-2: Percentage of emissions by activity categories was 39% of total flights, non-jet aircraft engines were responsible for 55% of hydrocarbons and 47% of carbon monoxide emissions from all aircraft engines. The percentage of emissions from non-jet aircraft engines for oxides of nitrogen and sulfur oxides are 17% and 32% respectively. Figure 4-1, and 4-2 (a)~(d) show the percentages of LTO cycles and emissions related to commercial jet flights, non-jet flights, and on-road vehicles. Emissions from ground support equipment were included in either commercial jet or non-jet flights depending on the aircraft assigned to the equipment.

The emissions from aircraft main engines were divided into take-off and landing operations and further subdivided into five operating modes. As shown in table 4-2, emissions from take-off operations were much higher than emissions from landing operations because of the higher fuel flow rate and longer taxi/idle time associated with take-off operations.

Aircraft Category	Operation	Mode	HC	CO	NO_X	SO_X
Commercial jet	Take-off	take-off	3.92	15.37	498.49	9.47
		climb-out	7.30	30.97	629.42	15.56
		taxi-out	428.88	1518.44	182.16	28.03
		total	440.10	1564.78	1310.06	53.06
	Landing	approach	20.66	111.50	160.24	10.81
		taxi-in	158.01	559.43	67.11	10.33
		total	178.67	670.93	227.35	21.01
Non-jet aircraft	Take-off	take-off	0.38	18.07	13.17	0.68
		climb-out	1.28	65.29	38.49	2.13
		taxi-out	540.48	1824.47	146.55	20.61
		total	542.14	1907.84	198.21	23.42
	Landing	approach	13.87	128.39	38.02	3.72
		taxi-in	200.15	676.55	54.01	7.59
		total	214.02	804.94	92.02	11.31

Table 4-2: Emissions from commercial jet and non-jet aircraft by operating modes, in tons of pollutant

The percentage of aircraft emissions from the taxi-out/idle operating mode was found to be very high for hydrocarbons and carbon monoxide. It is also interesting to note that the oxides of nitrogen emissions for this operating mode had the same order of magnitude as the take-off and climb-out operating modes.

4.1.2 Future Scenario

The future aircraft fleet after retirement of all stage 2 aircraft is said to be "clean" in terms of the air pollutant emissions. The result from the annual emission estimation with the assumed future fleet reconfirmed this point except for oxides of nitrogen. In the case that the air traffic activity was kept constant, hydrocarbon and carbon monoxide emissions were reduced while sulfur oxides emissions were essentially invariant. Oxides of nitrogen emission showed an increase.

In the case that a 10% increase in air traffic was assumed, total hydrocarbon emission still showed a decrease while all other species included in the study showed increases. The average emissions per LTO cycle for all aircraft is shown in table 4-3 and the result is summarized in Appendix J. There was no change in ground support equipment and aircraft auxiliary power units other than the 10% increase in activity, therefore all the emissions from these sources were increased by 10%. The emissions from on-road vehicles were decreased except for sulfur oxides. The emissions from aircraft main engines showed increases in all species except for hydrocarbons. The rates of increase in emissions relative to the increase in air traffic are about one-half times for carbon monoxide, and 1.5 times for oxides of nitrogen.

Year	HC	CO	NO_X	SO_X
1998	5.82	20.96	7.75	0.46
2010	5.01	20.10	8.17	0.46

Table 4-3: Average emissions per LTO cycle in 1998, in kg of pollutant

4.1.3 Result Comparison

The emissions from commercial jet main engines were compared to the previous study conducted on the subsonic commercial jet aircraft for the EPA (herein referred to as the EPA study). Of the 214,208 LTO cycles included in this study, 130,320 of them were related to commercial jet aircraft. The EPA study included 114,282 LTO cycles in its 1990 base year study. From these numbers of LTO cycles, the average annual increase during the eight years in the LTOs was calculated to be 1.66%. There was a difference in LTO cycles accounting for foreign flag carriers between the two studies. While the EPA study used the monthly summaries compiled by the Department of Transportation to add the number of LTO cycles due to foreign flag carriers, this study estimated the foreign flag LTO cycles from a published timetable. However, the induced error was expected to be small since the total number (both jet and non-jet aircraft) of LTO cycles related to foreign flag carriers was less than 6% in this study.

Table 4-4 summarizes the annual emissions estimations for 1990 from the EPA study and for 1998 from this study. The average emissions per LTO cycle, computed as total emissions divided by total number of LTO cycles, reconfirm that the average jet aircraft in commercial service has become cleaner. Yet, total emissions from aircraft engines increased as the air traffic increased during the eight years.

A similar comparison was made for the future emission estimations. Both studies had attempted to estimate the future emissions from jet aircraft main engines in 2010. The EPA study assumed the number of LTO cycles in 2010 to be 137,137, which made

Year	No. of LTO		HC	CO	NO_X	SO_X
1990	114,282	Total	875.81	2216.65	1359.73	63.91
		Per LTO	6.95	17.60	10.79	0.51
1998	130,320	Total	618.76	2235.71	1537.41	74.20
		Per LTO	4.31	15.56	10.70	0.52

Table 4-4: Estimated annual emissions from jet aircraft for 1990 and 1998, in tons of pollutant for total emissions, kg of pollutant for emissions per LTO

the average annual growth of 0.916% over 20 years. This study assumed there would be 143,364 commercial jet aircraft LTO cycles in 2010. The average annual growth rate over the 12 years would be 0.798%. The percent difference (difference divided by the average of the two) between the two estimated number of LTO cycles is approximately 4.4%.

The difference in the other major assumption, jet aircraft fleet in 2010, in the two studies perhaps has affected the difference in result more than the number of LTO cycles. While this study simply replaced all stage 2 aircraft (except for the freighters) with a single newer model with similar seat capacity and increased all aircraft activity uniformly, the EPA study used the activity-weighted average remaining aircraft to replace the stage 2 aircraft.

As shown in table 4-5, there are significant differences in average emissions per LTO cycle, thus the total emissions from jet aircraft main engines. The per LTO emissions in 2010 from the EPA study is worse than both 1998 and 1990 values presented above. After reviewing the methodology to determine the fleet turnover for 2010, the reason for the increase in average emissions is not yet clear. One explanation may be that the emission index of newer aircraft engines is decreasing, however, the emission rate is increasing as the fuel flow rate increases. It is particularly more probable when a smaller stage 2 aircraft was replaced with a much larger "average" remaining aircraft.

	No. of LTO		HC	CO	NO_X	SO_X
	143,364	Total	470.27	2237.71	1802.69	81.20
		Per LTO	2.98	14.16	11.41	0.51
EPA study	137,137	Total	1436.86	3318.84	2234.13	86.12
		Per LTO	9.51	21.95	14.78	0.57
Percent difference in per LTO emissions			108.6%	43.1%	25.7%	11.1%

Table 4-5: Estimated annual emissions from jet aircraft for 2010 by two studies, in tons of pollutant for total emissions, kg of pollutant for emissions per LTO

4.2 Dispersion Modeling

4.2.1 Calculated Pollutant Concentrations for September 5, 1999

The result from the dispersion calculation for September 5, 1999 shows that the ground-level emissions from airport mobile sources alone did not cause unacceptably high levels of carbon monoxide, oxides of nitrogen, or sulfur oxides concentrations downwind under the particular conditions. The worst concentrations calculated at breathing height during the 24-hour period are 8.74 PPM for 1-hour average carbon monoxide, 4.35 PPM for 8-hour average carbon monoxide, and 0.014 PPM sulfur oxides. These worst concentrations were observed mainly around the gate area. In general, there was no major difference between concentrations at breathing height and at gate height. The concentrations in gate areas were slightly higher at gate height than breathing height.

The hourly concentration plots for oxides of nitrogen, carbon monoxide, and sulfur oxides from 5 A.M. to 11 P.M. are included in Appendix I. The concentration peak observed for oxides of nitrogen for 6 A.M. is due to the combination of wind direction, gate location, and grid receptor location. Although none of the grid receptors coincides with the gate location, the wind direction is such that the grid receptor was located directly downwind of gate C making it almost the location of concentrated point sources. Concentrations calculated with an altered wind direction showed moderate values. Subsection 4.2.3 discusses the issue related to the concentrations near the gates.

Since the concentrations were calculated only for the model day, this result alone does not prove that the airport mobile source emissions will not cause unacceptably high pollutant concentrations at the airport and its immediate surroundings. Also it should be noted that the calculated concentrations do not include the background concentration. What is useful about the model day dispersion calculation is that now it can be used as the base result and compared to the dispersion calculations with a different set of input conditions. The next two sub-sections will discuss the dispersion calculation results with different meteorological conditions and reduced emission sources.

4.2.2 Effect of Meteorological Conditions on the Calculated Pollutant Concentrations

Figure 4-3 (a) and (b) both show NO_X concentrations at 10:00 A.M.: (a) is for the actual wind speed and (b) is for low-wind speed. The concentration at (-1500, -500) for the low-wind condition has an out-of-scale value of 1.202 PPM. However, the concentration scale for low-speed wind conditions was not adjusted to accommodate the peak value in order to make the concentration comparison between the actual and low-wind speed conditions more effective. All other grid points in the low-speed conditions have concentrations less than 0.5 PPM.

The concentration peaks in both figure 4-3 (a) and 4-3 (b) are located downwind near the gates, the runway entrance and on the runway itself. The maximum concentration location in the low-wind speed calculation was found at the runway 9 entrance. Here, oxides of nitrogen emissions were high due to the take-off engine setting and the amount of traffic. Note that most of the aircraft were assumed to take off from runway 9. The second highest concentration was found on the midpoint of runway 9. It should be noted that in reality the pollutants were continuously emitted during take-off.

The differences in concentrations between actual and low-wind speed calculations are solely due to the differences in meteorological conditions, namely the wind speed and PG stability class. The amount of emissions and source locations were identical for both cases. In this particular hour, a decrease in 4 m/s in wind speed produced an increase in concentrations reaching a maximum of up to 20 times in the area downwind of the source. The typical difference factor, defined as concentration for low-wind conditions divided by the concentration for actual meteorological conditions, is in the range of 5 to 15. In general, these difference-factors increase as the distance from the emission sources increases. When the wind speed is higher the concentration decays quickly as it travels downwind. With a lower wind speed this decay in pollutant concentration takes place considerably slower.

The worst computed 8-hour carbon monoxide concentration for low-wind conditions was approximately 7.6 PPM. Compared to the actual-day condition, the top worst 8-hour carbon monoxide concentrations were increased by a factor of 1.5. The top worst 3-hour sulfur oxide concentrations for low-wind speed conditions which has the maximum value of 0.0232 PPM show a similar increase. The typical locations which experienced these worst concentrations were near the gates and runway entrances.

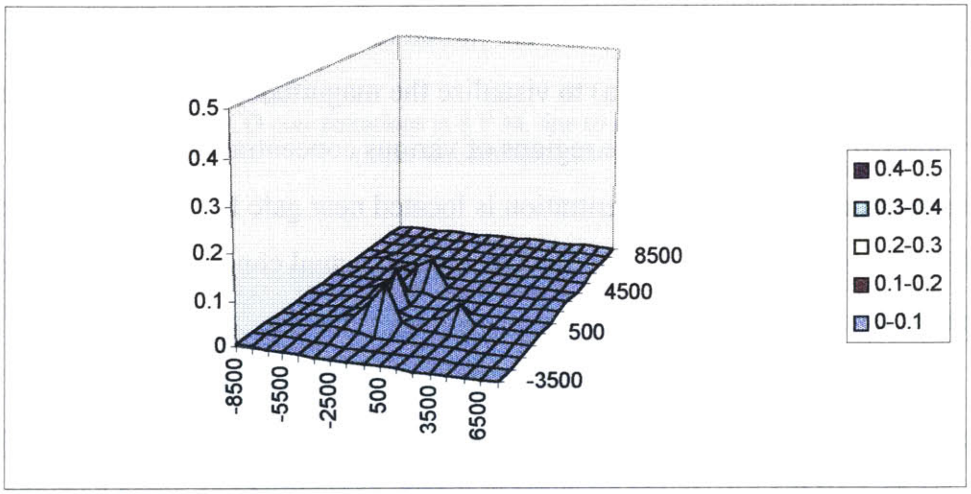


Figure 4-3(a): Calculated NO_X concentrations at 10 A.M. using actual meteorological conditions

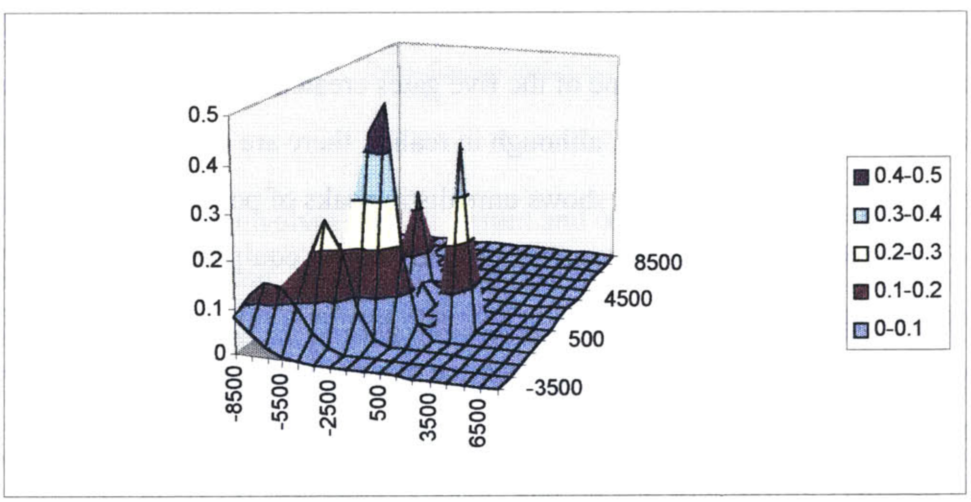


Figure 4-3(b): Calculated NO_X concentrations at 10 A.M. using low-wind speed meteorological conditions

4.2.3 Emissions from Ground Support Equipment

The result from the dispersion calculations with and without ground support equipment showed that the contribution of ground support equipment to the local air quality was significant, particularly for carbon monoxide. The "local" referred to here is mainly around the gates and the area downwind of the gates. The airport and aircraft operation crews and passengers have continuous access to these areas. The complete result from 5 A.M. to 11 P.M. is included in Appendix I.

The difference in concentrations for carbon monoxide at 8 P.M. was plotted three-dimensionally in figure 4-4 (a) to visualize the magnitude, and two-dimensionally in figure 4-4 (b) to clearly show the regions of various concentration differences. The maximum peak difference in concentration is located near gate B. The smaller peak is located downwind of gates C, D, and E. The plots of actual concentrations are included in Appendix I.

The result shows that carbon monoxide emissions due to ground support equipment affects the air quality not only near the gates but also in the general terminal areas extending all the way to the edge of the gridded boundary. In some portions of the region described above, ground support equipment is responsible for 80-95% of carbon monoxide concentrations which is up to 1.5 PPM.

A few issues must be addressed before any conclusions are drawn from the result. First, in the dispersion calculation, all ground support equipment and aircraft auxiliary power units were situated at any one of the five gates created in the model. This means there is only one gate per terminal, although in reality, there are many gates for each terminal. Consequently, the result shows unrealistic peaks of pollutant concentrations near the gates where emission sources (i.e. ground support equipment and auxiliary power units) were concentrated. A single auxiliary power unit is fixed at a gate and is a point source. Ground support equipment service to a particular aircraft can be modeled reasonably as a point source since its activity area is bounded near the gate. However, a group of auxiliary power units and ground support equipment servicing multiple aircraft have the characteristics of area source because they are a collection of point sources placed over an area rather than a single point.

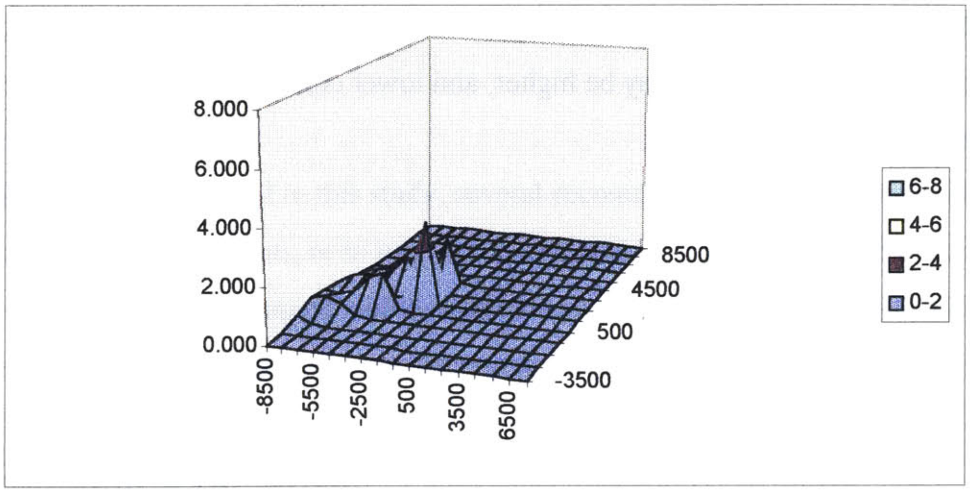


Figure 4-4 (a): Difference in CO concentrations at 8 P.M. due to emissions from ground support equipment (three-dimensional view)

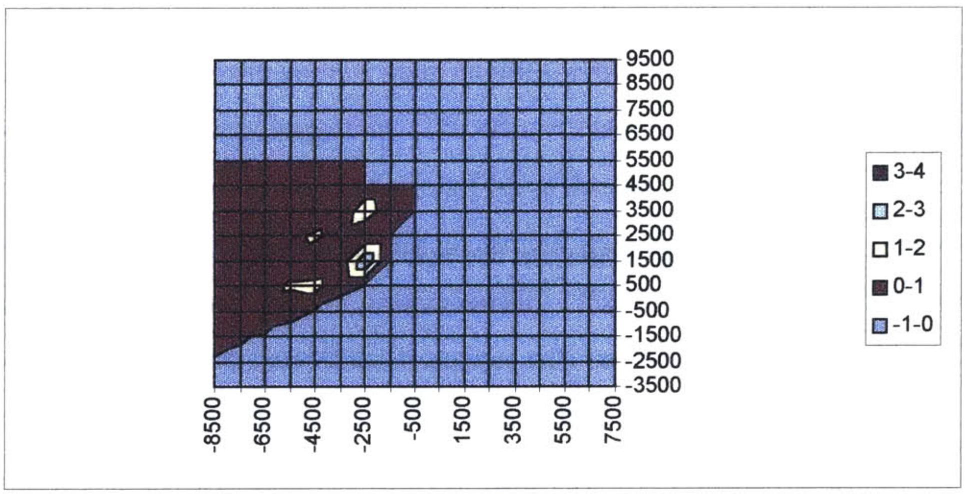


Figure 4-4 (b): Difference in CO concentrations at 8 P.M. due to emissions from ground support equipment (two-dimensional view)

The second issue involves the flat terrain and one-dimensional air flow assumed in the dispersion calculation. In general, errors are introduced when the Gaussian dispersion equation is used for ground-level release of pollutant because the wind speed varies rapidly with altitude. Moreover, the local air flow around airport terminal buildings is far more complex than a simple one-dimensional, or two-dimensional flow. The concentrations were calculated at the typical breathing height of 5.9 feet, which is obviously much lower than the terminal building height. When the separation and reattachment of the air flow, schematically described in figure 4-5, occurs, the concentrations near the gates may be higher, and lower concentrations on the other side of the building may be observed.

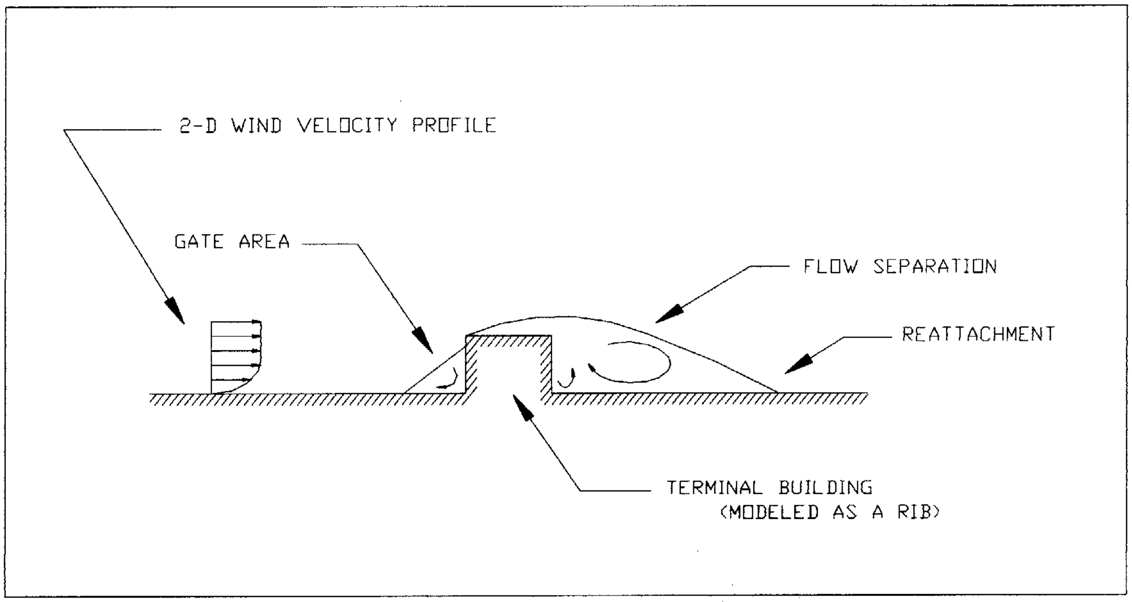


Figure 4-5: Schematic two-dimensional flow over terminal building (modeled as a rib)

4.2.4 Future Scenario

The results from dispersion analysis for the future scenario with a 10% increase in traffic showed some increases in air pollutants concentrations. There were approximately 10% increases in hourly maximum concentrations for oxides of nitrogen. Generally, increases in carbon monoxide hourly maximum concentrations were slightly less than those of oxides of nitrogen for a given hour. The greatest increase in the sulfur oxides hourly maximum concentration was 33%, while some hours did not show any increase.

These increases in maximum concentrations are summarized in Appendix J. The maximum hourly concentrations for present day and future cases were generally found on the same grid point for a given pollutant and a given hour with a few exceptions.

5. Recommendations

From the analysis conducted in this study, several recommendations were made either to reduce air pollutant emissions, or to improve future studies and air quality evaluations. All recommendations were made with a hope to improve air quality at airports without discouraging the growth and further development of commercial aviation.

5.1 Emission Reductions

5.1.1 Aircraft Engines

Taxi-Out Efficiency

For emission reduction from aircraft main engines, efficient taxiing, especially for taxi-out prior to take-off, is very important. The efficient taxi-out/idle means here a shorter average time spent from the moment aircraft leave the gate to the moment of their take-off. For example, if the taxi-out time for all aircraft included in the annual emission estimation is three minutes shorter, approximately 11% of hydrocarbon and carbon monoxide emissions from aircraft main engines will be eliminated. The oxides of nitrogen and sulfur oxides emission reduction will be 2.8% and 7.1% respectively. An efficient taxi-out is also important for reducing delay, which is becoming a common problem at major airports. Taxi operation is the easiest operation to modify and facility-based solutions can be sought. Some commercial software and consulting work are available to improve taxi efficiency.

Single- or Reduced-Engine Taxi

Concerning taxi-out, single-engine taxiing or reduced-engine taxiing is an effective way to reduce emissions during the taxi-out/idle operating mode. During the single-engine taxiing or reduced-engine taxiing, one or more engines are shutdown. Since adequate power for taxiing is generally available from a single engine at idle power setting, an aircraft can taxi with a single engine at idle without significantly increasing the emissions of that engine. If all aircraft in the 1998 study that have more than one engine use one less engine to taxi out, the emission reduction from aircraft main engines will be 37.9% for hydrocarbons, 36.3% for carbon monoxide, 9.7% for oxides of nitrogen, and 24.0% for sulfur oxides. These percentages correspond to 35.0%, 18.5%, 8.0% and 21.9% of emissions, species in the same order as above, from all sources included in this study.

If all aircraft in 2010 as defined in this study use one less engine to taxi out, the total emissions from airport mobile sources for carbon monoxide decreases despite a 10% increase in traffic. In addition, the increase in oxides of nitrogen emissions will also be less. Table 5-1 summarizes the emission estimations for 1998 and 2010. The percent changes of 2010 emissions relative to the 1998 estimate are shown in figures 5-1 and 5-2.

The practice of single- or reduced-engine taxiing varies depending on the air carrier. Some carriers adopt it as standard operations while others do not either encourage or discourage this practice according to the Natural Resources Defense Council. Whenever single- or reduced-engine taxiing do not conflict with safety, it should be routinely practiced not only from an emission reduction standpoint, but also from a cost reduction standpoint.

Year	Emission Source	HC	CO	NO_X	SO_X
1998	**All sources**	1525.98	10092.24	2243.15	121.57
	Aircraft	1381.61	5084.04	1901.08	108.96
2010	**All sources**	1458.88	10791.02	2568.40	133.27
	Aircraft	1309.77	5370.43	2201.40	119.40
2010	**All sources**	1028.98	9139.67	2391.70	108.76
(reduced-engine)	**Aircraft**	879.87	3719.08	2024.70	94.89

Table 5-1: Selected annual emission estimations for 1998 and 2010

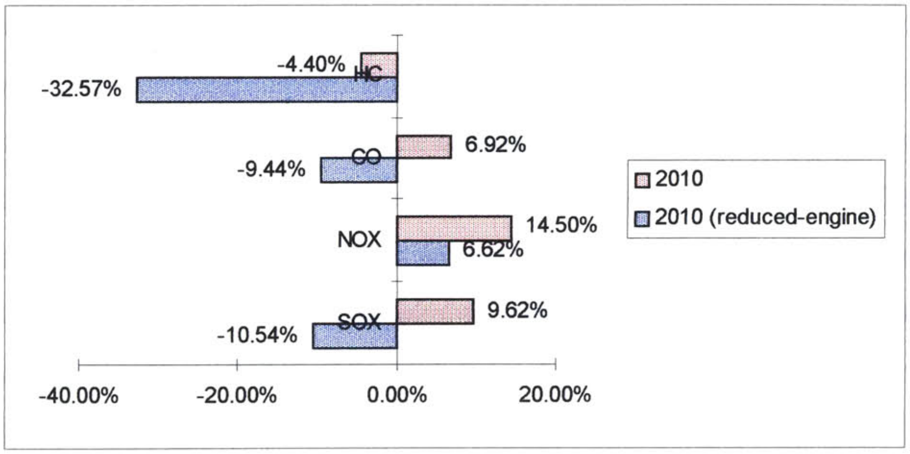


Figure 5-1: Change in annual emission from airport mobile sources relative to 1998 estimate

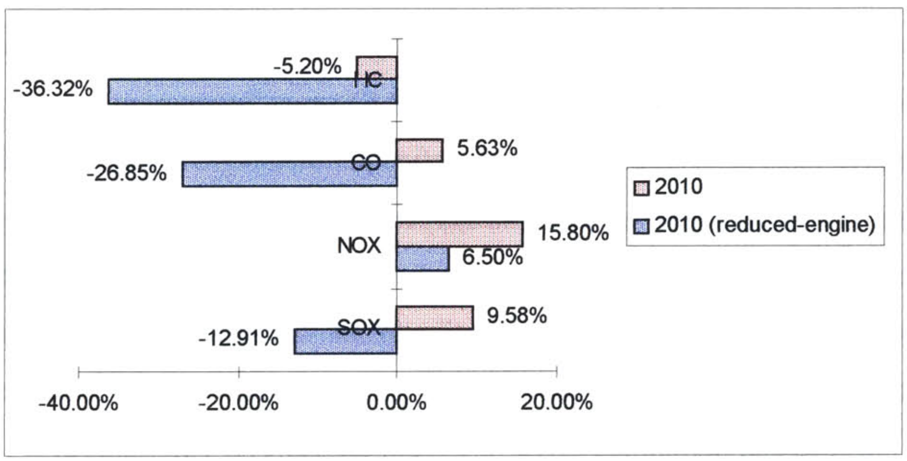


Figure 5-2: Change in annual emission from aircraft relative to 1998 estimate

5.1.2 Ground Support Equipment

It was suggested in a previous study that the emissions from ground support equipment can be reduced by employing alternative fuels or electric power. While the average aircraft main engines will be clean in terms of their air pollutant emissions except for oxides of nitrogen, the total emissions from these sources are expected to increase, except for hydrocarbons, as the demand for commercial flights increases. The potential reduction in emissions from ground support equipment is significant enough to counter-balance these increases especially for carbon monoxide, thus preventing an increase in total ground-level emissions from airport mobile sources. In the case assumed in this study, 13.8% reduction in carbon monoxide emissions from ground support equipment will prevent the total emissions from increasing in 2010. By replacing the conventional equipment with electric counterpart, for example, the potential carbon monoxide reduction can be over 90%. It is much more difficult to counter-balance the increase in oxides of nitrogen emissions by reducing the contributions from ground support equipment. Only the potential reduction by replacing *all* conventional ground support equipment with electric counterpart may have the possibility. The following paragraphs discuss the alternative fuel and electric powered ground support equipment as well as the fixed gate support system briefly.

Alternative Fuel and Electric Powered Ground Support Equipment

The alternative fuels considered here are liquefied petroleum gas or compressed natural gas. Relative to gasoline-powered ground support equipment, emissions of non-methane hydrocarbons, oxides of nitrogen, carbon monoxide, particulate matter, and carbon dioxide will generally be reduced by converting to alternative-fuel-powered ground support equipment. Relative to diesel-powered ground support equipment, emissions of oxides of nitrogen and particulate matter are reduced, however emissions of hydrocarbons and carbon monoxides are increased. Carbon dioxide emission will be either slightly increased or decreased depending on the equipment size.

Electric ground support equipment do not emit pollutants on site, instead emissions from off-site power generating stations will be increased due to the higher demand of electric power. However, even when the increased off-site emissions are considered, the use of electric ground support equipment usually results in significantly less emissions of hydrocarbons, carbon monoxide, oxides of nitrogen, particulate matter, and carbon dioxide than fossil-fuels, including the alternative fuels-powered counterparts. The air quality around gates should be expected to improve significantly if electric powered ground support equipment are used.

Fixed Gate Support

Fixed gate support is a point-of-use support system designed into airport gates. A previous study points out that a significant fraction of ground support equipment can be replaced by this alternative support system. One advantage is that the fixed gate support allows the facility to use hard-wired electrical power connections. As for electric ground support equipment, use of fixed gate support equipment increases off-site emissions by demanding a higher amount of electric power. However, it is likely that fixed gate support equipment consume less power than equivalent mobile ground support equipment since the motive aspect of operation is eliminated.

Although there are substantial initial costs associated with fixed gate support systems, some fixed gate support equipment are cost effective and an increasing number of airports have already installed such equipment, namely gate-based power and conditioned air systems. The operating time for aircraft auxiliary power units or ground support equipment counterparts can be significantly reduced by these fixed gate support systems.

Other types of fixed gate support equipment are much less feasible since they are not cost effective and installation to existing airports is a challenge. This equipment includes stationary fuel, water and lavatory hookups, centralized baggage conveyors, and automated aircraft pushback systems.

5.2 Future Improvement

5.2.1 Future Analysis

Air Quality Monitoring Around Gates and Terminals

Air quality around gates and terminals is of some concern since these areas are frequently accessed by passengers as well as airport and air carrier crews. In general, these public access areas are located near emission sources and should receive additional attention. The complicated geometry around these areas makes it difficult to predict the air quality with the simple dispersion model used in this study, therefore the results only suggest the potential impact of airport mobile sources on the air quality around these areas. The terminal buildings, roadway structure and overhang, if existing, and idling on-road vehicles, all add to the complexity of pollutant movements. A further facility-level analysis involving more in-depth modeling and air quality monitoring during unfavorable meteorological conditions can be the tools to access the air quality in these areas and to seek a solution if the air quality is determined to be inadequate. This further analysis will add to the understanding of air quality levels and should be useful to predict the future effects when the demand for air travel increases.

Non-Jet Aircraft

Non-jet aircraft, mostly those powered by turbo-propeller engines, may have received less attention than jet aircraft for their potential environmental impact. However, it was found that non-jet aircraft have a significant share of hydrocarbon and carbon monoxide emissions. Unless the specific interest is only oxides of nitrogen emissions (even though non-jet aircraft have some less significant contribution here, too) or non-jet aircraft traffic is very low, the future studies should pay attention to non-jet aircraft and jet aircraft alike.

The significance of helicopters and other rotor aircraft on the ground-level air pollution emissions was not investigated in this study. If a specific airport expects a fair amount of aircraft traffic from these types of aircraft, the emissions from these sources should be investigated.

5.2.2 Supportive Information and Tools

Emission Factor Measurement

The common emission species measured and found in various aircraft engine emission databases are unburned hydrocarbons, carbon monoxide, and oxides of nitrogen (NO_X). The extensive measurement of two other species is desirable; sulfur oxides (SO_X) and particulate matter.

Sulfur oxide emissions from aircraft engines are often calculated based on the national average sulfur content of aviation fuels, assumed to be in the form of sulfur dioxide; the same method used in this study. As a result, many different aircraft engines are assumed to have the same emission factor (g of pollutant per kg of fuel). This does not seem reasonable since the other measured pollutants show a wide range of emission factors. At least some measurement to validate the order of magnitude for the emission factors and assumed pollutant species should be conducted.

Ground Support Equipment Database

It was pointed out in a previous study regarding emissions from ground support equipment that currently there is no nationwide database to estimate the population of ground support equipment. Ground support equipment are not required to register and essentially they are left unregulated. As a result, this study assumed that a default set of ground support equipment was used for a particular type of aircraft operation and activity level was measured with an operational time per LTO cycle. If more accurate analysis is required, it would be up to the aircraft operators to provide the necessary information. For both future emission regulations and air quality studies, it seems more desirable for an appropriate independent private agent or public organization to have a ground support equipment database which includes essential information such as the use of equipment, fuel type, annual fuel consumption, and emission factors.

Approved Algorithms for Approach and Climb-out

As stated previously, there are no approved dispersion algorithms for aircraft in the modes of approach and climb-out at this time. For this reason, aircraft emissions during climb-out mode and the entire landing operations were not included in the dispersion modeling. Development of approved algorithms or incorporating existing algorithms into a dispersion analysis software recommended by a regulatory agent is strongly recommended.[1]

The annual emission estimation shows that the percentages of these missing pollutants account for 29.2% of hydrocarbons, 31.8% of carbon monoxide, 54.0% of oxides of nitrogen, and 46.0% of sulfur oxides emissions from total aircraft main

[1]A plan to incorporate algorithms for approach and climb-out has been indicated by the EDMS developing team.

engines. If the emissions during taxi-in are included in the dispersion calculation, the hydrocarbon and carbon monoxide concentrations are expected to show an increase while oxides of nitrogen concentration may not show a significant difference.

The effect of emissions during approach mode is least likely to be seen in the air pollutant concentrations at airports especially when aircraft descend directly into the wind. Given that the relative amount of these emissions are low (2.1% for hydrocarbon, 4.8% for carbon monoxide, 10.8% for oxides of nitrogen, and 13.4% for sulfur oxides), the direct impact on the air quality downwind of the descent path is also expected to be small.

The impact of emissions during climb-out may be seen at airports and/or its surroundings, which should be thoroughly investigated to predict the air quality level in the future. An airport is typically located downwind of the climb-out path and climb-out mode has the maximum contribution of the oxides of nitrogen emissions from aircraft main engines. On the other hand, a typical climb-out path stretches out a few miles, which may imply that the indirect impact of these emissions through atmospheric chemical reactions have more significance than the direct impact on concentrations.

Appendix A

National Ambient Air Quality Standards

Pollutant	Measurement method	Value (PPM)	(µg/m3)	Standard type**
Carbon monoxide	8-hour average	9	10 *	Primary
	1-hour average	35	40 *	Primary
Lead	Quarterly average		1.5	Primary & secondary
Nitrogen dioxide	Annual arithmetic mean	0.053	100 *	Primary & secondary
Ozone	1-hour average	0.120	235 *	Primary & secondary
	8-hour average	*0.08*	*157* *	*Primary & secondary*
Particulate matter (PM-10)	24-hour average		150	Primary & secondary
	Annual arithmetic mean		50	Primary & secondary
Particulate matter (PM-2.5)	*24-hour average*		*15*	*Primary & secondary*
	Annual arithmetic mean		*65*	*Primary & secondary*
Sulfur dioxide	24-hour average	0.140	365 *	Primary
	Annual arithmetic mean	0.03	80 *	Primary
	3-hour average	0.500	1300 *	Secondary

Source: Environmental Protection Agency
*The value is an approximately equivalent concentration.
**Primary standards are air quality standards required to prevent any adverse impact on human health. Secondary standards are air quality standards required to prevent adverse effects on vegetation, property, or other elements of the environment.
***The standards in Italics are for information only. A 1999 federal court ruling blocked implementation of these standards which were proposed by the EPA in 1997.
****All standards are as of November 15, 1990

Appendix B

Annual Number of LTO Cycles by Operators and Aircraft Type, Engine Assignment, and Percent Share

Carrier	Aircraft	No. of LTO	Engine type 1	% share	Engine type 2	% share	Engine type 3	% share
Air Transport	* DC-8-63F	5	JT3D-7	100%				
	* DC-8-62	6	JT3D-3B	29%	JT3D-7	71%		
	* DC-8-71	21	CFM56-2C	100%				
Airtran Airways	737-100/200	129	JT8D-15	11%	JT8D-9A	56%	JT8D-17	33%
	DC-9-10	2409	JT8D-7B	100%				
	DC-9-30	287	JT8D-7B	59%	JT8D-9A	39%	JT8D-9	2%
America West Airlines	737-300	116	CFM56-3B2	48%	CFM56-3B1	50%	CFM56-3C1	2%
	757-200	1383	RB211-535E4	100%				
	A320-200	822	V2527-A5	32%	V2500-A1	68%		
	737-100/200	1	JT8D-9A	22%	JT8D-15	78%		
	A319	3	V2524-A5	100%				
American Airlines	FOKKER 100	1990	TAY 650-15	100%				
	757-200	5097	RB211-535E4-B	100%				
	767-200	718	CF6-80A	27%	CF6-80A2	73%		
	767-300	45	CF6-80C2B6	80%	CF6-80C2B6	20%		
	MD-80	5938	JT8D-219	13%	JT8D-217	35%	JT8D-217C	52%
	A300-600	2326	CF6-80C2A5	100%				
	DC-10-10	1	CF6-6K	100%				
	MD-11	19	CF6-80C2D1F	100%				
	727-200	5	JT8D-9A	73%	JT8D-15	27%		
American International	* 727-200	11	JT8D-9A	100%				
	* L-1011/100/20	58	RB211-524B-02	100%				
	* 747	3	JT9D-7A	38%	JT9D-7J	50%	JT9D-7F	13%
	* DC-8-63F	13	JT3D-7(H)	100%				
	* DC-8-62	189	JT3D-3B(H)	100%				
	* DC-8-50F	2	JT3D-3B	100%				
	* DC-8-61	1	JT3D-3B	100%				
	L-1011-100-20	12	RB211-524B-02	100%				
	747	2	JT9D-7A	67%	JT9D-7J	33%		
American Trans Air	727-200	7	JT8D-17A	53%	JT8D-17R	26%	JT8D-17	21%
	+ 727-200	2	JT8D-15	40%	JT8D-7B	60%		
	L-1011-500	1	RB211-524B4	100%				
	757-200	13	RB211-535E4	89%	PW2040	11%		
	L-1011/100/20	139	RB211-22B	100%				
Amerijet International	* 727-100	2	JT8D-7B	100%				
	* 727-200	4	JT8D-9A	20%	JT8D-15	70%	JT8D-17	10%
Carnival	737-400	103	CFM56-3C	100%				

Carrier	Aircraft	No. of LTO	Engine type 1	% share	Engine type 2	% share	Engine type 3	% share
Carnival *(cont'd)*	737-100/200	3	JT8D-9A	100%				
	727-200	123	JT8D-15	100%				
Champion Air	727-200	6	JT8D-17	100%				
Continental Airlines	ATR-42	1	PW127E	21%	PW121	79%		
	737-500	893	CFM56-3C1	100%				
	737-300	1642	CFM56-3B1	100%				
Continental Airlines	737-100/200	7	JT8D-9A	100%				
	737-200C	18	JT8D-9A	100%				
	MD-80	6997	JT8D-217	35%	JT8D-217A	54%	JT8D-219	12%
	727-200	5	JT8D-9A	67%	JT8D-17	20%	JT8D-17R	13%
	+ 727-200	5	JT8D-15	100%				
	DC-10-30	4	CF6-50C2	83%	CF6-0C2B	13%	CF6-50C1	4%
	+ DC-10-30	2	CF6-50C	50%	CF6-50C2R	50%		
	757-200	2	RB211-535E4-B	100%				
	DC-9-30	22	JT8D-15	27%	JT8D-9A	73%		
Delta Air Lines	737-100/200	5355	JT8D-15	6%	JT8D-15	7%	JT8D-15A	87%
	757-200	4311	PW2037	100%				
	767-200	319	CF6-80A	87%	CF6-80A2	13%		
	767-300	1090	CF6-80A2	37%	PW4060	54%	CF6-80C2B4	9%
	+ 767-300	252	CF6-80C2B6F	93%	CF6-50C2B7	7%		
	MD-80	2225	JT8D-219	100%				
	727-200	7161	JT8D-9A	8%	JT8D-15	92%		
	L-1011/100/20	626	RB211-22B	100%				
	L-1011-500	526	RB211-524B4	100%				
	MD-11	1	PW4460	100%				
DHL Airways	* 727-100	257	JT8D-7B	100%				
	* 727-200	6	JT8D-7	33%	JT8D-7B	50%	JT8D-15	17%
	+ * 727-200	4	JT8D-17R	58%	JT8D-9A	42%		
	* DC-8-73	1	CFM56-2C	100%				
Eastwind Airlines	737-100/200	600	JT8D-9A	100%				
	737-300	167	CFM56-3B	100%				
Emery Worldwide	* 727-100C/QC	32	JT8D-7B	100%				
	* 727-200	542	JT8D-9A	27%	JT8D-7B	73%		
	* DC-8-63F	10	JT3D-7	100%				
	* DC-8-71	188	CFM56-2C	100%				
	* DC-8-73F	302	CFM56-2C	100%				
	* DC-8-62	146	JT3D-3B	100%				

Carrier	Aircraft	No. of LTO	Engine type 1	% share	Engine type 2	% share	Engine type 3	% share
Emery Worldwide *(cont'd)*	* DC-8-50F	1	JT3D-3B	100%				
Express One	DC-9-30	6	JT8D-7B	100%				
	* 727-200	144	JT8D-9A	76%	JT8D-17A	6%	JT8D-17R	18%
	+* 727-200	17	JT8D-15	100%				
Federal Express	* BEECH 18	579	TPE331-1-101B	100%				
	* C-208	19	PT6A-114	62%	PT6A-114A	38%		
	* A300-600	136	CF6-80C2A5	100%				
	* A310-200	169	CF6-80A3	64%	JT9D-7R4E1	36%		
	* 727-100	250	JT8D-7B	100%				
	* 727-200	45	JT8D-7B	12%	JT8D-217C	65%	JT8D-17A	24%
	+* 727-200	210	JT8D-15	76%	JT8D-17	16%	JT8D-9A	8%
	* DC-10-10	299	CF6-6K	31%	CF6-6D	65%	CF6-6D1A	4%
	* DC-10-30	572	CF6-50C2	18%	CF6-50C2	82%		
	* MD-11	74	CF6-80C2D1F	100%				
Fine Air	* DC-8-50F	1	JT3D-3B	100%				
Flagship Airlines	ATR-42	203	PT6A-45	100%				
	SF-340	34	CT7-5	100%				
Frontier Airlines	737-300	333	CFM56-3B2	11%	CFM56-3C1	67%	CFM56-3B1	22%
Gemini Air Cargo	* DC-10-30	1	CF6-50C2	100%				
Kittyhawk Air Cargo	* 727-200	122	JT8D-7B	28%	JT8D-15	20%	JT8D-9	52%
	+* 727-200	40	JT8D-9A	100%				
	727-200	120	JT8D-15	100%				
Laker Airways	DC-10-30	6	CF6-50C2	100%				
Miami Air	727-200	45	JT8D-15	86%	JT8D-15A	14%		
Midway Airlines	FOKKER 100	1425	TAY 650-15	100%				
	CAN RJ-100 ER	14	CF34-3A1	100%				
	A320-200	226	V2500-A1	20%	V2527-A5	80%		
	CAN RJ-200 ER	131	CF34-3B1	100%				
Midwest Express Airlines	DC-9-10	357	JT8D-7B	100%				
	DC-9-30	1434	JT8D-9A	75%	JT8D-7B	25%		
Nations Air	727-200	58	JT8D-15	100%				
North American Airlines	757-200	188	RB211-535E4	100%				
	737-800/900	9	CFM56-7B26	100%				
Northwest Airlines	757-200	2350	PW2037	100%				
	DC-9-10	5	JT8D-7B	100%				
	DC-9-30	236	JT8D-9A	51%	JT8D-7B	34%	JT8D-17	15%
	DC-9-40	165	JT8D-11	100%				

Carrier	Aircraft	No. of LTO	Engine type 1	% share	Engine type 2	% share	Engine type 3	% share
Northwest Airlines *(cont'd)*	DC-9-50	513	JT8D-17	100%				
	A320-200	1359	CFM56-5A1	100%				
	727-200	576	JT8D-7B	6%	JT8D-15	78%	JT8D-17	16%
	+ 727-200	72	JT8D-17R	100%				
	DC-10-30	185	CF6-50C2B	20%	CF6-50C	65%	CF6-50C2	15%
	DC-10-40	798	JT9D-20J	48%	JT9D-20	52%		
	MD-80	1	JT8D-217	100%				
	747-200	2	JT9D-7F	33%	JT9D-7Q	50%	JT9D-7R4G2	17%
	747-400	1	PW4056	100%				
Pace	737-100/200	1	JT8D-9A	67%	JT8D-7B	33%		
Panagra Airways	727-100	1	JT8D-7B	100%				
	727-200	1	JT8D-9A	100%				
Reliant Airlines	* FALCON	46	CF700-2D2	92%	TFE731-2-1C	8%		
Ryan International Airlines	727-200	28	JT8D-15	25%	JT8D-9A	50%	JT8D-7B	25%
	727-100	3	JT8D-7B	100%				
	* 727-100	3	JT8D-7B	100%				
	* 727-200	5	JT8D-7B	100%				
	A320-200	1	CFM56-5B4	67%	CFM56-5A3	17%	V2500-A1	17%
Sierra Pacific Airlines	737-100/200	18	JT8D-17	100%				
Simmons	ATR-42	1511	PT6-45	100%				
	SF-340	1153	CT7-5	100%				
Sky Trek International Airlines	727-200	128	JT8D-7B	40%	JT8D-15	40%	JT8D-17R	20%
Spirit Airlines	DC-9-30	320	JT8D-9A	33%	JT8D-7B	56%	JT8D-9	11%
	+ DC-9-30	35	JT8D-11	100%				
	MD-80	8	JT8D-219	67%	JT8D-217	17%	JT8D-217C	17%
Sun Country Airlines	727-200	308	JT8D-17R	42%	JT8D-17	25%	JT8D-217C	33%
	DC-10-10	7	CF6-50C2F	100%				
Sun Pacific International	727-200	1	JT8D-9A	83%	JT8D-17R	17%		
Sunworld International Airlines	727-200	1	JT8D-17	50%	JT8D-15	50%		
Tower Air	747	9	JT9D-7J	36%	JT9D-7A	57%	CF6-50E2	7%
	+ 747	2	JT9D-7Q	100%				
Tradewinds Airlines	L-1011/100/20	52	RB211-22B	100%				
Trans Continental Airlines	* DC-8-50F	1	JT3D-3B	100%				
	* DC-8-62	1	JT3D-3B	100%				
Trans State Airlines	JETSTREAM 41	3667	TPE331-14HR-805H	100%				
Trans World Airlines	757-200	223	PW2037	100%				
	767-200	4	JT9D-7R4D	75%	PW4060	25%		

Carrier	Aircraft	No. of LTO	Engine type 1	% share	Engine type 2	% share	Engine type 3	% share
Trans World Airlines *(cont'd)*	DC-9-30	2	JT8D-9A	100%				
	DC-9-50	1	JT8D-17	100%				
	MD-80	1714	JT8D-217A	25%	JT8D-217C	17%	JT8D-219	58%
	727-200	552	JT8D-9A	87%	JT8D-15	13%		
Transmeridian Airlines	A320-200	51	V2500-A1	75%	V2527-A5	25%		
	727-100	16	JT8D-15	100%				
United Airlines	737-500	1138	CFM56-3C1	100%				
	737-300	1795	CFM56-3B1	57%	CFM56-3B2	43%		
	737-100/200	141	JT8D-17	71%	JT8D-9A	29%		
	757-200	4740	PW2040	6%	PW2037	94%		
	767-200	1217	JT9D-7R4D	100%				
	767-300	137	PW4060	100%				
	A320-200	2645	V2527-A5	100%				
	727-200	853	JT8D-15	100%				
	A319	354	V2522-A5	100%				
UPS Airlines	* 727-100	118	TAY 651-54	100%				
	* DC-8-71	286	CFM56-2C	100%				
	* DC-8-73	382	CFM56-2C	100%				
	* 757-200	107	RB211-535E4	53%	PW2040	47%		
	* 767-300	13	CF6-80C2B7F	100%				
	727-100	96	TAY 651-54	100%				
US Airways	FOKKER 100	2690	TAY 650-15	100%				
	737-400	2928	CFM56-3B2	100%				
	737-300	3961	CFM56-3B2	56%	CFM56-3B1	44%		
	757-200	2420	RB221-535E4	29%	RB221-535E4	71%		
	DC-9-30	7007	JT8D-9A	48%	JT8D-7B	52%		
	MD-80	2119	JT8D-217	100%				
	767-200	7	CF6-80C2B2	100%				
USA Jet Airlines	* DC-9-15F	2	JT8D-7B	100%				
	* FALCON	7	CF700-2D2	100%				
US Airways Shuttle	727-200	5547	JT8D-7B	67%	JT8D-9A	33%		
Valuejet	DC-9-10	547	JT8D-7B	100%				
	DC-9-30	266	JT8D-7B	100%				

Carrier	Aircraft	No. of LTO	Engine type 1	% share	Engine type 2	% share	Engine type 3	% share
Non-U.S. Carriers (estimate)								
Air Canada	A319-114	2140	CFM56-5A5	100%				
	CR JET 100ER	1631	CF34-3A1	87%	CF34-3B1	13%		
	DC-9-32	102	JT8D-7A	100%				
Air Nova	DHC-8-102 Dash 8	3058	PW120A	100%				
Air France	767-300ER	357	PW4060	60%	CF6-80C2B6F	40%		
Alitalia	767-33A(ER)/36M(ER)	357	CF6-80C2B6F	100%				
British Airways	747-136/236B/436	713	JT9D-7A	11%	RB211-524D4	20%	RM211-524H2	69%
	777-236/236ER	357	GE90-85B	69%	TRENT 895	17%	GE90-76B	14%
Canadian	737-200s	255	JT8D-17	43%	JT8D-9A	43%	JT8D-17A	14%
	A320-211/212	357	CFM56-5A1	92%	CFM56-5A3	8%		
Canadian Regional Airlines	F28 FELLOWSHIP 1000	1070	SPEY 555-15N	58%	SPEY 555-15	42%		
Air Lingus	A330-301/302	357	CF6-80E1A2	71%	CF6-80E1A4	29%		
Icelandair	757-200s/308	357	RB211-535E4	82%	RB211-535E4B	18%		
Korean Air	747-400	153	PW4056	100%				
Olympic Airways	747-212B/284B	102	JT9D-7J	25%	JT9D-7Q	75%		
Sabena	A330-301/223/322	51	CF6-80E1A2	30%	PW4168	10%	PW4168A	60%
	A340-211/311	306	CFM56-5C2	100%				
Swissair	757-357	357	JT9D-7R4G2	100%				
Tap Air Portugal	A310-304	102	CF6-80C2A2	100%				
Virgin Atlantic	747-200s/400s	357	RB211-524D4	100%				
Commuters (estimate)								
Cape Air	CESSNA 402 II	9708	TSIO-520-VB	100%				
American Eagle Airlines	ATR42-300	2140	PW120	100%				
	SF340	1427	CT7-9B	100%				
Colgan Air	BH1900C-1/1900D	1172	PT6A-65B	75%	PT6A-67D	25%		
Comair Airlines	CL-600s	2497	CF34-3A1	100%				
Business Express Airlines	SF340A/340B	36284	CT7-5A2	53%	CT7-9B	47%		
Atlantic Coast Airlines	BAE JETSTREAM 32	306	TPE331-12UAR-701H	100%				
	BAE JETSTREAM 41	2191	TPE331-14HR-805H	100%				
US Airways Shuttle	BH1900D	15339	PT6A-67D	100%				
	DHC-8-102 Dash 8	5096	PW120A	100%				

Source: Department of Transportation, OAG Worldwide

Appendix C

Ground Support Equipment Assignments

	Ground Support Equipment/ Auxiliary Power Unit	Operation Time per LTO cycle (min.)	Aircraft*
Group 1	APU GTCP 85 (200 hp)	26	727**
	Diesel Aircraft Tug Narrow	6	737
	Diesel Belt Loader	48	757**
	Diesel Cabin Service	15	A310**
	Diesel Food Truck	35	A319
	Diesel Lavatory Truck	20	A320
	Diesel Fuel Truck	35	A330
	Gasoline Baggage Tug	85	CANADAIR REGIONAL JET
			DC-9**
			F-28
			FOKKER 100
			MD-80
			RJ145ER/LR
Group 2	APU GTCP 660 (300 hp)	26	747**
	Diesel Aircraft Tug Wide	8	767**
	Diesel Airstart Transporter	3	777
	Diesel Airstart Unit	3	A300-600**
	Diesel Belt Loader	48	A340
	Diesel Cabin Service	15	DC-10**
	Diesel Container Loader	92	L-1011**
	Diesel Food Truck	35	MD-11**
	Diesel Fuel Truck	35	
	Diesel Lavatory Truck	20	
	Diesel Transporter	10	
	Diesel Water Truck	12	
	Gasoline Baggage Tug	85	
Group 3	Diesel Aircraft Tug Narrow	6	BAE Jetstream 32
	Diesel Fuel Truck	35	BH-1900
	Gasoline Baggage Tug	85	
	Gasoline Ground Power Unit	30	
Group 4	Diesel Fuel Truck	10	Cessna 402C II
	Gasoline Baggage Tug	20	
Group 5	APU GTCP 36 (85 hp)	26	ATR-42
	Diesel Aircraft Tug Narrow	6	DHC-8-100
	Diesel Belt Loader	48	SF340
	Diesel Cabin Service	15	
	Diesel Food Truck	35	
	Diesel Fuel Truck	35	
	Diesel Lavatory Truck	20	
	Gasoline Baggage Tug	85	
Group 6	APU GTCP 85 (200 hp)	26	727 freighter
	Diesel Aircraft Tug Narrow	6	757 freighter
	Diesel Belt Loader	48	A310 freighter
	Diesel Container Loader	92	DC-8 freighter
	Diesel Fuel Truck	35	DC-9 freighter
	Diesel Lavatory Truck	20	

	Ground Support Equipment/ Auxiliary Power Unit	Operation Time per LTO cycle (min.)	Aircraft*
Group 7	APU 660 (300 hp)	26	747 freighter
	Diesel Aircraft Tug Wide	8	767 freighter
	Diesel Airstart Transporter	3	A300-600 freighter
	Diesel Airstart Unit	3	DC-10 freighter
	Diesel Belt Loader	48	L-1011 freighter
	Diesel Container Loader	92	MD-11 freighter
	Diesel Fuel Truck	35	
	Diesel Lavatory Truck	20	
Group 8	Diesel Aircraft Tag Narrow	6	BEECH 18 freighter
	Diesel Belt Loader	48	FALCON freighter
	Diesel Fuel Truck	35	
	Gasoline Ground Power Unit	30	
Group 9	Diesel Fuel Truck	10	C-208 freighter
	Gasoline Baggage Tug	30	
Group 10	Diesel Aircraft Tug Narrow	6	BAE Jetstream 41
	Diesel Fuel Truck	35	
	Diesel Lavatory Truck	10	
	Gasoline Baggage Tug	85	
	Gasoline Ground Power Unit	30	

* Includes all series except where noted

** Includes all series except freighters

Appendix D

Air Carrier Gate Assignments

Terminal	Carrier
Terminal A	Cape Air
	Continental Airlines
	Frontier Airlines
	Midwest Express Airlines
Terminal B	America West Airlines
	American Airlines
	American Eagle Airlines
	Business Express
	Canadian Airways
	MetroJet
	Midway Airlines
	US Airways
	US Airways Shuttle
	US Airways Express
Terminal C	Air France
	Comair
	Delta Air Lines
	Delta Express
	Trans World Airlines
	Trans World Connection
	United Airlines
	United Express
Terminal D	Airtran Airways
	DHL Airways
Terminal E	Air Lingus
	Air Canada
	Air Nova
	Alitalia
	British Airways
	Iceland Air
	KLM
	Korean Air
	Lufthansa
	Northwest Airlines
	Olympic Airways, S.A.
	Sabena, S.A.
	Sun Country Airlines
	Swissair
	TAP Air Portugal
	Virgin Atlantic

Appendix E

Aircraft Main Engine Substitutions

Original Engine Model	Substitute Engine Model
AE3007A1/2	AE3007A1
CF34-3B1	CF34-3A1
CT7-5A2	CT7-5
CT7-9B	CT7-5
PT6A-67D	PT6A-67B
RB211-524H2	RB211-524H
Spey 555-15N	Spey 555
TPE331-12UAR-7	TPE331-3
TSIO-520-VB	TSIO-360C

Appendix F

Emission Factors for Aircraft Main Engines

Engine model	HC Emission Factors (g of HC/kg of fuel) Take off	Climb out	Approach	Idle	CO Emission Factors (g of CO/kg of fuel) Take off	Climb out	Approach	Idle	NO_X Emission Factors (g of NO_X/kg of fuel) Take off	Climb out	Approach	Idle
AE3007A	0.25	0.29	0.64	2.51	0.75	0.92	3.28	17.35	20.54	17.47	7.79	3.83
CF34-3A1	0.06	0.06	0.13	3.95	0	0	1.9	42.6	11.61	10.14	6.86	3.82
CF6-50C	0.6	0.7	1	23	0.5	0.5	5.2	62.3	35	29	9.4	3.5
CF6-50C1, -C2	0.6	0.7	1.0	21.8	0.5	0.5	4.3	61.8	36.3	29.7	9.5	3.6
CF6-50C2B	0.13	0.15	0.26	2.72	0.46	0.44	3.42	24.04	29.59	26.34	10.49	3.40
CF6-50C2R	0.6	0.7	1.0	23.0	0.5	0.5	5.2	62.3	35.0	29.0	9.4	3.5
CF6-50E2	0.6	0.7	1.0	21.8	0.5	0.5	4.3	61.8	36.3	29.7	9.5	3.6
CF6-6D	0.3	0.3	0.7	21.0	0.5	0.5	6.5	54.2	40.0	32.6	11.4	4.5
CF6-6D1A	0.3	0.3	0.6	19.9	0.5	0.5	5.5	52.0	41.6	33.9	11.8	4.6
CF6-6K	0.3	0.3	0.7	21.0	0.5	0.5	6.5	54.2	40.0	32.6	11.4	4.5
CF6-80A	0.29	0.29	0.47	6.29	1.0	1.1	3.1	28.2	29.8	25.6	10.3	3.4
CF6-80A2	0.30	0.37	0.45	6.28	1.0	1.1	2.8	28.2	29.6	26.6	10.8	3.4
CF6-80A3	0.30	0.37	0.45	6.28	1.0	1.1	2.8	28.2	29.6	26.6	10.8	3.4
CF6-80C2A2	0.08	0.1	0.23	10.48	0.57	0.55	2.94	46.01	27.93	20.69	9.44	3.95
CF6-80C2A5	0.07	0.08	0.2	8.99	0.52	0.52	1.93	41.65	30.85	22.86	9.11	3.79
CF6-80C2A5	0.04	0.05	0.11	1.48	0.06	0.04	1.91	18.89	28.57	21.69	12.53	4.76
CF6-80C2B2	0.08	0.10	0.22	11.17	0.57	0.55	2.65	48.02	23.89	18.65	8.77	3.7
CF6-80C2B4	0.08	0.09	0.21	9.74	0.56	0.54	2.33	43.91	29.20	21.80	8.90	3.67
CF6-80C2B6	0.07	0.08	0.2	8.99	0.52	0.52	1.93	41.66	30.81	22.94	9.11	3.79
CF6-80C2B6	0.04	0.05	0.11	1.48	0.06	0.04	1.91	18.89	28.57	21.69	12.53	4.76
CF6-80C2B6F	0.07	0.08	0.19	9.74	0.52	0.52	1.92	43.89	32.16	23.09	9.06	3.75
CF6-80C2B6F	0.05	0.05	0.11	1.43	0.05	0.04	1.93	18.42	27.38	21.05	12.63	4.81
CF6-80C2B7F	0.05	0.05	0.11	1.43	0.05	0.04	1.93	18.42	27.38	21.05	12.63	4.81
CF6-80C2D1F	0.07	0.08	0.20	9.03	0.52	0.52	1.94	41.78	32.65	24.02	9.16	3.8
CF6-80E1A2	0.05	0.07	0.14	9.37	0.38	0.34	1.61	42.67	39.29	28.02	9.91	4.53
CF6-80E1A2	0.04	0.04	0.11	1.25	0.05	0.04	1.85	17.37	28.72	22.01	12.66	4.88
CF700-2D	0.1	0.1	1.4	18	22	27	62	155	5.6	4.4	1.8	0.9
CFM56-2-C5	0.04	0.05	0.08	1.83	0.9	0.9	4.2	30.7	18.5	16.0	8.2	4
CFM56-3B	0.04	0.05	0.08	1.25	0.9	0.9	3.1	27	20.7	17.3	8.7	4.1
CFM56-3B1	0.04	0.05	0.08	2.28	0.9	0.95	3.8	34.4	17.7	15.5	8.3	3.9
CFM56-3B2	0.036	0.047	0.073	1.75	0.9	0.9	3.4	30.1	19.4	16.7	8.7	4.1
CFM56-3C	0.05	0.05	0.08	2.86	0.9	1.0	4.2	38.1	16.6	14.7	8.0	3.8
CFM56-3C1	0.03	0.04	0.07	1.42	0.9	0.9	3.1	26.8	20.7	17.8	9.1	4.3
CFM56-5A1	0.23	0.23	0.4	1.4	0.9	0.9	2.5	17.6	24.6	19.6	8	4

Engine model	Fuel Flow Rate (kg/s) Take off	Climb out	Approach	Idle	Remarks*
AE3007A	0.377	0.315	0.117	0.049	Data obtained from the Federal Aviation Administration
CF34-3A1	0.407	0.3343	0.119	0.0496	
CF6-50C	2.379	1.915	0.643	0.212	Test dates from 12 Oct 79 to 05 Dec 79
CF6-50C1, -C2	2.487	1.975	0.660	0.215	Test dates from 12 Oct 79 to 05 Dec 79
CF6-50C2B	2.410	1.997	0.667	0.163	Idle emission factors measured at lower than standard (i.e. 7% of rated output) throttle setting
CF6-50C2R	2.379	1.915	0.643	0.212	Test dates from 12 Oct 79 to 05 Dec 79
CF6-50E2	2.487	1.975	0.660	0.215	Test dates from 12 Oct 79 to 05 Dec 79
CF6-6D	1.736	1.431	0.4839	0.1728	
CF6-6D1A	1.812	1.502	0.494	0.176	
CF6-6K	1.736	1.431	0.4839	0.1728	
CF6-80A	2.145	1.795	0.615	0.150	
CF6-80A2	2.254	1.885	0.641	0.150	
CF6-80A3	2.254	1.885	0.641	0.150	
CF6-80C2A2	2.117	1.745	0.58	0.189	Test dates from 29 May 85 to 03 Jun 85
CF6-80C2A5	2.581	2.082	0.687	0.207	Test dates from 29 May 85 to 03 Jun 85
CF6-80C2A5	2.580	2.096	0.672	0.205	Test dates from 13 Jan 95 to 17 Jan 95
CF6-80C2B2	2.131	1.761	0.577	0.192	Test dates from 29 May 85 to 03 Jun 85
CF6-80C2B4	2.430	1.982	0.650	0.199	Test dates from 29 May 85 to 03 Jun 85
CF6-80C2B6	2.579	2.081	0.686	0.207	Test dates from 29 May 85 to 03 Jun 85
CF6-80C2B6	2.580	2.096	0.672	0.205	Test dates from 13 Jan 95 to 17 Jan 95
CF6-80C2B6F	2.540	2.020	0.643	0.1963	Test dates from 29 May 85 to 03 Jun 85
CF6-80C2B6F	2.594	2.104	0.682	0.203	Test dates from 13 Jan 95 to 17 Jan 95
CF6-80C2B7F	2.594	2.104	0.682	0.203	Test dates from 13 Jan 95 to 17 Jan 95
CF6-80C2D1F	2.596	2.065	0.657	0.196	Test dates from 29 May 85 to 03 Jun 85
CF6-80E1A2	2.767	2.245	0.724	0.228	Test dates from 08 Jun 92 to 04 Aug 92
CF6-80E1A2	2.767	2.245	0.724	0.228	Test dates from 13 Jan 95 to 17 Jan 95
CF700-2D	0.328	0.276	0.116	0.058	Data obtained from the Federal Aviation Administration
CFM56-2-C5	0.985	0.819	0.311	0.128	
CFM56-3B	1.142	0.932	0.3608	0.1303	Data obtained from the Federal Aviation Administration
CFM56-3B1	0.946	0.792	0.29	0.114	
CFM56-3B2	1.056	0.878	0.314	0.119	
CFM56-3C	0.872	0.732	0.273	0.111	Rerated
CFM56-3C1	1.154	0.954	0.336	0.124	
CFM56-5A1	1.051	0.862	0.291	0.1011	

Engine model	HC Emission Factors (g of HC/kg of fuel)				CO Emission Factors (g of CO/kg of fuel)				NO_X Emission Factors (g of NO_X/kg of fuel)			
	Take off	Climb out	Approach	Idle	Take off	Climb out	Approach	Idle	Take off	Climb out	Approach	Idle
CFM56-5A3	0.2	0.2	0.3	1.3	0.9	0.9	2.4	16.2	26.4	21.1	8.3	4.1
CFM56-5A5	0.23	0.23	0.45	1.53	1.1	1.1	2.8	18.5	24.79	19.98	8.94	4.29
CFM56-5B4	0.10	0.10	0.13	3.87	0.50	0.50	2.33	31.90	28.7	23.3	10.0	4.3
CFM56-5C2	0.008	0.008	0.082	5.68	0.93	0.80	1.75	34.0	32.6	25.8	10.0	4.2
CFM56-7B24	0.1	0.1	0.1	2.4	0.4	0.6	2.2	22	25.3	20.5	10.1	4.4
CFM56-7B26	0.1	0.1	0.1	1.9	0.2	0.6	1.6	18.8	28.8	22.5	10.8	4.7
CT7-5	1	1	1.5	4	2.5	2.7	5.3	35.4	13.8	13.2	6.9	2.2
GE90-76B	0.07	0.06	0.67	3.42	0.09	0.13	5.80	40.35	44.86	35.39	12.68	5.88
GE90-85B	0.08	0.07	1.52	3.05	0.08	0.12	25.35	37.83	52.01	40.27	10.3	6.01
JT3D-3B	4.0	2.0	4.0	112.0	1.5	2.8	24.5	98.0	12.1	9.9	4.8	2.5
JT3D-7 series	-	-	-	-	-	-	-	-	-	-	-	-
JT8D-11	0.40	0.45	1.4	10.0	1.2	1.9	9.4	35.0	18.9	14.6	5.8	2.75
JT8D-15	0.25	0.25	1.65	11	0.7	1	9.6	35.2	19.1	15	5.9	3
JT8D-15	0.24	0.28	0.55	1.46	1.03	1.15	2.77	11.0	19.4	15.1	6.9	3.2
JT8D-15A	0.25	0.33	0.65	1.86	1.08	1.2	2.9	12.93	18.1	13.9	6.6	3.1
JT8D-17	0.69	0.79	1.96	10.2	0.74	1	8.54	31	19.2	15.23	6.1	3.3
JT8D-17A	0.25	0.30	0.64	6.6	1.07	1.16	2.88	12.46	19.1	14.3	6.7	3.2
JT8D-17R	0.21	0.27	0.53	0.95	0.95	1.03	2.54	9.43	25.3	17.6	8.4	3.3
JT8D-217 series	0.28	0.43	1.6	3.33	0.8	1.23	4.17	12.27	25.7	20.6	9.1	3.7
JT8D-219	0.27	0.42	1.59	3.48	0.73	1.2	4.07	12.63	27	20.8	9.13	3.6
JT8D-7 series	0.4	0.5	1.6	10.6	1.5	2	10.5	35.5	17.1	13.5	5.5	2.7
JT8D-7 series	0.25	0.25	0.4	3.8	0.9	1.1	2.2	14.3	17.2	14.0	6.3	3.15
JT8D-9 series	0.47	0.47	1.73	10	1.24	1.66	9.43	34.5	17.92	14.21	5.64	2.9
JT9D-20	0.1	0.1	1.3	36.1	0	0	7.6	83.6	38.7	28.5	7.6	3.1
JT9D-20J	0	0	0.5	24.5	0.9	0.9	5.5	66.7	44.9	34.9	9.4	3.3
JT9D-7A	0.1	0.1	1.3	36.1	0	0	7.6	83.6	38.7	28.5	7.6	3.1
JT9D-7F	0.3	0.3	0.5	26.0	0.4	0.4	2.9	54.0	46.0	34.4	7.8	3.1
JT9D-7J	0	0	0.5	24.5	0.9	0.9	5.5	66.7	44.9	34.9	9.4	3.3
JT9D-7Q	0.2	0.2	0.3	12.0	0.2	0.2	1.7	53.0	31.6	25.6	7.8	3
JT9D-7R4D	0.15	0.12	0.13	1.25	0.51	0.48	1.36	8.84	38.5	30	9.8	4.1
JT9D-7R4E, -7R4E1	0.16	0.13	0.13	1.11	0.57	0.53	1.23	8.27	41.6	34.2	10.4	4.1
JT9D-7R4G2	0.15	0.14	0.18	1.55	0.74	0.63	1.4	11.82	41.3	29.5	8.8	3.8
PT6A-41	1.75	2.03	22.71	101.63	5.1	6.49	34.8	115.31	7.98	7.57	4.65	1.97
PT6A-45	0	0	0	3.402	0.71	0.94	4.796	21.01	9.694	9.004	6.2	4.002

Engine model	Fuel Flow Rate (kg/s) Take off	Climb out	Approach	Idle	Remarks*
CFM56-5A3	1.131	0.925	0.307	0.1044	
CFM56-5A5	0.972	0.799	0.276	0.098	
CFM56-5B4	1.166	0.961	0.326	0.107	
CFM56-5C2	1.308	1.076	0.3558	0.1175	
CFM56-7B24	1.103	0.91	0.316	0.109	
CFM56-7B26	1.221	0.999	0.338	0.113	
CT7-5	0.101	0.094	0.045	0.015	Data obtained from the Federal Aviation Administration
GE90-76B	2.83	2.33	0.78	0.30	Test dates from 24 Feb 95 to 28 Jul 95
GE90-85B	3.19	2.6	0.85	0.3	Test dates from 24 Feb 95 to 28 Jul 95
JT3D-3B	1.174	0.932	0.346	0.135	Emissions data estimated from JT3D-7 engines using JT3D-3B performance data.
JT3D-7 series	1.254	1.032	0.389	0.128	Smoke fix combustor 14-70KC. Applicable to JT3D-7, -7A.
JT8D-11	1.121	0.9136	0.3339	0.1455	Reduced Emissions Combustor incorporated 1/1/84
JT8D-15	1.178	0.945	0.3403	0.1477	Smoke fix combustor in production prior to 1/1/84
JT8D-15	1.178	0.9450	0.3402	0.1477	Reduced Emissions Combustor incorporated 1/1/84
JT8D-15A	1.115	0.8955	0.312	0.1372	
JT8D-17	1.245	0.997	0.354	0.147	Smoke fix combustor in production prior to 1/1/84
JT8D-17A	1.173	0.9344	0.3304	0.1401	Reduced emissions combustor incorporated 1/1/84
JT8D-17R	1.417	1.103	0.3755	0.155	
JT8D-217 series	1.32	1.078	0.3833	0.1372	SCH 46-16B combustor. Applicable to JT8D-217, -217A, -217C.
JT8D-219	1.354	1.085	0.3817	0.1344	
JT8D-7 series	0.9892	0.8113	0.2861	0.1291	Smoke fix combustor in production prior to 1/1/84. Applicable to JT8D-7, -7A, -7B.
JT8D-7 series	0.9892	0.8113	0.2861	0.1291	Reduced emissions combustor. Applicable to JT8D-7, -7A, -7B.
JT8D-9 series	1.04	0.846	0.298	0.132	Smoke fix combustor in production prior to 1/1/84. Applicable to JT8D-9, -9A.
JT9D-20	2.099	1.789	0.619	0.211	Emissions estimated from JT9D-7 engines using JT9D-7A performance data.
JT9D-20J	2.315	1.902	0.679	0.238	
JT9D-7A	2.099	1.789	0.619	0.211	Emissions estimated from JT9D-7 engines using JT9D-7A performance data.
JT9D-7F	2.1672	1.7640	0.6237	0.2190	Mod V combustor. Test dates from Nov 75 to Dec 75
JT9D-7J	2.315	1.902	0.679	0.238	
JT9D-7Q	2.4419	1.9996	0.6804	0.2370	
JT9D-7R4D	2.055	1.678	0.7593	0.2054	
JT9D-7R4E, -7R4E1	2.118	1.724	0.6529	0.2210	
JT9D-7R4G2	2.429	1.88	0.659	0.2239	
PT6A-41	0.0643	0.0596	0.0344	0.0185	Data obtained from the Environmental Protection Agency
PT6A-45	0.0801	0.0708	0.0398	0.0207	Data obtained from the Federal Aviation Administration

Engine model	HC Emission Factors (g of HC/kg of fuel)				CO Emission Factors (g of CO/kg of fuel)				NO_X Emission Factors (g of NO_X/kg of fuel)			
	Take off	Climb out	Approach	Idle	Take off	Climb out	Approach	Idle	Take off	Climb out	Approach	Idle
PT6A-65B	0	0	3.798	22.02	4.7	6.403	21.79	66.06	7	6.6	4.5	2.9
PT6A-67B	0	0	3.299	22.982	4.497	6.103	21	68.946	7	6.6	4.5	2.8
PW 120	0	0	0	0	2	2.301	6	14.882	13.8	12.3	8.1	5.69
PW 120A	0	0	0	0	2	2.301	6	14.882	13.6	12.3	6.1	5.69
PW121	0	0	0	0	2	2.3	5.7	13.606	13.8	12.2	8.3	6.9
PW127E	0	0	0	0	2.1	2.1	3.5	9.301	16.8	15	9.4	6.6
PW2037	0.05	0.06	0.21	2.26	0.4	0.41	2.3	23.1	31.1	24.8	10.3	4.4
PW2040	0.026	0.035	0.18	2.25	0.4	0.4	2	25.1	34.3	27.3	10.6	4.2
PW4056	0.06	0.01	0.13	1.92	0.44	0.57	2	21.86	28.1	22.9	11.6	4.8
PW4060	0.1	0.03	0.14	1.66	0.37	0.51	1.8	20.32	32.8	24.7	12	4.9
PW4168	0.03	0.04	0.15	3.29	0.72	0.74	1.75	23.51	42.39	33.91	14.66	4.15
PW4168A	0.03	0.04	0.15	3.29	0.72	0.74	1.75	23.51	42.39	33.91	14.66	4.15
PW4460	0.1	0.03	0.14	1.66	0.37	0.51	1.78	20.32	32.8	24.7	12	4.9
RB211-22B	0.36	0.39	7.73	65.37	2.48	4.14	26.38	93.17	34.32	25.63	8.05	2.7
RB211-524B4	0.52	0.4	4.98	50.6	1.83	2.82	20	82.2	47	33	9.8	3.5
RB211-524D4	0	0.42	4.8	46.46	0.51	1.18	16.9	73.8	56.9	41	9.65	4.11
RB211-524H	0.34	0.33	0.36	0.74	0.87	0.38	0.99	11.75	65.84	46.31	10.26	4.78
RB211-535E4	0.04	0.01	0.04	1	1.01	1.23	1.71	15.44	52.7	36.2	7.5	4.3
RB211-535E4	0	0.01	0.04	0.37	0.77	0.5	1.14	13.31	44.88	32.06	6.78	3.46
RB211-535E4-B	0.01	0	0.03	0.28	0.94	0.6	1.05	11.76	54.46	36.82	7.35	3.52
Spey 555	0.15	0.22	0.33	3.41	1.54	2.08	5.78	31.16	17.33	13.06	5.05	2.23
Tay 650-15	0.37	0.41	0.88	3.29	1.74	2.01	6.54	33.77	19.81	16.47	4.55	1.7
TAY 651	0.56	0.37	0.85	3.1	1.68	1.93	6.11	32.68	20.31	17.13	4.77	1.72
TAY Mk650-15	0.37	0.41	0.88	3.29	1.74	2.01	6.54	33.77	19.81	16.47	4.55	1.7
TFE731-2	0.11	0.13	4.26	20.04	1.39	2.03	22.38	58.6	15.25	13.08	5.9	2.82
TPE331-3	0.11	0.15	0.64	79.11	0.76	0.98	6.96	61.52	12.36	11.86	9.92	2.86
Trent 892	0.01	0	0	0.7	0.28	0.2	0.57	13.07	45.7	33.3	11.58	5.33
TSIO-360C	9.17	9.55	11.31	138.26	1081.95	950.8	995.08	592.17	2.71	4.32	3.77	1.91
V2500-A1	0.1	0.11	0.15	0.22	0.55	0.55	0.77	7.76	37.13	30.82	13.45	5.91
V2522-A5	0.041	0.041	0.062	0.103	0.57	0.67	2.6	13.42	24.5	20.8	8.7	4.5
V2524-A5	0.042	0.042	0.061	0.1	0.54	0.63	2.37	12.64	26.2	22	9	4.7
V2527-A5	0.041	0.041	0.061	0.105	0.53	0.62	2.44	12.43	26.5	22.3	8.9	4.7

Source: Defense Evaluation and Research Agency of the United Kingdom's Ministry of Defense, except where noted.

* Only those test dates that were used in the study to determine the appropriate emission factors are shown. See chapter 2 for details.

Engine model	Fuel Flow Rate (kg/s) Take off	Climb out	Approach	Idle	Remarks*
PT6A-65B	0.54	0.5402	0.5397	0.5405	
PT6A-67B	0.5397	0.5403	0.5399	0.5396	Data obtained from the Federal Aviation Administration
PW 120	0.54	0.5402	0.5399	0.5394	Data obtained from the Federal Aviation Administration
PW 120A	0.54	0.5402	0.5397	0.5394	Data obtained from the Federal Aviation Administration
PW121	0.1355	0.115	0.0836	0.0448	Data obtained from the Federal Aviation Administration
PW127E	0.1532	0.1351	0.0821	0.0505	Data obtained from the Federal Aviation Administration
PW2037	1.538	1.266	0.399	0.141	
PW2040	1.761	1.448	0.493	0.155	
PW4056	2.342	1.93	0.658	0.208	Data from X698-5 with reduced smoke combustor.
PW4060	2.647	2.085	0.703	0.213	
PW4168	2.836	2.327	0.798	0.221	Data from X821-3 with Floatwall Combustor
PW4168A	2.836	2.327	0.798	0.221	
PW4460	2.647	2.085	0.703	0.213	Data from X698-5 with reduced smoke combustor.
RB211-22B	1.866	1.542	0.553	0.277	Package 1 combustor. Test dates from Jun 79 to Aug 79
RB211-524B4	2.383	1.939	0.693	0.272	Package 1 Combustor. Applicable to RB211-524B, B2, B3, B4.
RB211-524D4	2.51	2.010	0.74	0.3	Package 1 combustor
RB211-524H	2.73	2.17	0.71	0.26	
RB211-535E4	1.86	1.51	0.57	0.19	
RB211-535E4	1.86	1.51	0.52	0.18	
RB211-535E4-B	2.08	1.65	0.55	0.19	
Spey 555	0.735	0.593	0.221	0.0964	Transply IIF combustors with standard fuel pump
Tay 650-15	0.874	0.715	0.254	0.119	
TAY 651	0.87	0.72	0.26	0.12	Test dates from Mar 88 to Oct 89
TAY Mk650-15	0.874	0.715	0.254	0.119	
TFE731-2	0.2055	0.1733	0.0671	0.024	Data obtained from the Federal Aviation Administration
TPE331-3	0.0577	0.0516	0.0315	0.0141	Data obtained from the Federal Aviation Administration
Trent 892	3.91	3.1	1	0.3	
TSIO-360C	0.0168	0.0125	0.0077	0.0014	Data obtained from the Federal Aviation Administration
V2500-A1	1.11	0.92	0.33	0.12	
V2522-A5	0.971	0.817	0.311	0.118	
V2524-A5	1.042	0.868	0.328	0.123	
V2527-A5	1.053	0.88	0.319	0.128	

Appendix G

Emission Factors for Ground Support Equipment and Aircraft Auxiliary Power Unit

Ground Support Equipment	Fuel Type	Emission Factors (kg/hr) HC	CO	NO_X	SO_X	PM-10
Airstart Unit	Diesel	0.648	2.160	5.940	0.135	0.270
Aircraft Tug Narrow	Diesel	0.168	0.560	1.540	0.035	0.070
Aircraft Tug Wide	Diesel	0.480	1.600	4.400	0.100	0.200
Airstart Transporter	Diesel	0.041	0.207	0.216	0.005	0.016
Belt Loader	Diesel	0.023	0.090	0.248	0.007	0.016
Cabin Service	Diesel	0.044	0.221	0.232	0.006	0.017
Container Loader	Diesel	0.044	0.221	0.231	0.006	0.017
Food Truck	Diesel	0.059	0.295	0.309	0.008	0.023
Fuel Truck	Diesel	0.054	0.180	0.495	0.011	0.023
Lavatory Truck	Diesel	0.044	0.221	0.232	0.006	0.017
Transporter	Diesel	0.044	0.221	0.232	0.006	0.017
Water Truck	Diesel	0.044	0.221	0.232	0.006	0.017
Baggage Tug	Gasoline	0.220	13.200	0.220	0.140	0.000
Ground Power Unit	Gasoline	0.450	27.000	0.450	0.029	0.000

Source: Federal Aviation Administration

Auxiliary Power Unit	Emission Factors (kg/hr) HC	CO	NO_X	SO_X	PM-10
GTCP 36 (80HP)	0.025601	0.26241	1.292838	N/A	N/A
GTCP 85 (200 HP)	0.109922	1.91992	0.506926	N/A	N/A
GTCP 660 (300 HP)	0.109596	3.38573	2.086236	N/A	N/A

Source: Federal Aviation Administration

Appendix H

Aircraft Hourly Operational Profiles

	Aircraft model	Engine model	Number of Departures Peak hour	Daily total	12-12:59A.M.	1-1:59A.M.	2-2:59A.M.	3-3:59A.M.
Gate A	737-300s	CFM56-3C1	1	1	0.00	0.00	0.00	0.00
	737-3T0/3Q8	CFM56-3B1	1	6	0.00	0.00	0.00	0.00
	737-522	CFM56-3C1	2	12	0.00	0.00	0.00	0.00
	737-724	CFM56-7B24	1	1	0.00	0.00	0.00	0.00
	757-224/224ET	RB211-535E4B	1	1	0.00	0.00	0.00	0.00
	BH1900C-1/1900D	PT6A-65B	2	8	0.00	0.00	0.00	0.00
	Cessna 402C II	TSIC-520-VB	4	37	0.00	0.00	0.00	0.00
	DC-9-14/15	JT8D-7B	1	1	0.00	0.00	0.00	0.00
	MD-81/82/83	JT8D-217A	2	17	0.00	0.00	0.00	0.00
	MD-81/82/88	JT8D-217C	1	3	0.00	0.00	0.00	0.00
	RJ145LR	AE3007A1/2	1	3	0.00	0.00	0.00	0.00
Gate B	727-225/227/254	JT8D-7B	1	17	0.00	0.00	0.00	0.00
	737-200s	JT8D-15	4	18	0.00	0.00	0.00	0.00
	737-200s	JT8D-17	1	1	0.00	0.00	0.00	0.00
	737-301/3B7	CFM56-3B2	6	48	0.00	0.00	0.00	0.00
	737-401/4B7	CFM56-3B2	2	9	0.00	0.00	0.00	0.00
	737-823	CFM56-7B26	1	5	0.00	0.00	0.00	0.00
	757-223	RB211-535E4-B	3	8	0.00	0.00	0.00	0.00
	757-225/2B7 (US)	RB211-535E4	3	10	0.00	0.00	0.00	0.00
	767-223	CF6-80C2B6	2	4	0.00	0.00	0.00	0.00
	767-323ER	CF6-80C2B6	1	1	0.00	0.00	0.00	0.00
	A300-605R	CF6-80C2A5	1	4	0.00	0.00	0.00	0.00
	A319-132	V2524-A5	1	2	0.00	0.00	0.00	0.00
	A320-211	CFM56-5A1	1	1	0.00	0.00	0.00	0.00
	A320-232 (HP)	V2527-A5	2	5	0.00	0.00	0.00	0.00
	ATR 42-300	PW120	2	6	0.00	0.00	0.00	0.00
	BH1900D	PT6A-67D	6	51	0.00	0.00	0.00	0.00
	CR Jet 200ER	CF34-3B1	1	1	0.00	0.00	0.00	0.00
	DC-9-31/32	JT8D-7B	2	9	0.00	0.00	0.00	0.00
	DHC-8-102 Dash 8	PW120A	2	15	0.00	0.00	0.00	0.00
	F28 Fellowship 1000	Spey 555-15N	1	3	0.00	0.00	0.00	0.00
	Fokker 100	Tay 650-15	2	11	0.00	0.00	0.00	0.00
	MD-80 Luxuary Jet	JT8D-217A	2	18	0.00	0.00	0.00	0.00

	Aircraft model	Engine model	4-4:59A.M.	5-5:59A.M.	6-6:59A.M.	7-7:59A.M.	8-8:59A.M.	9-9:59A.M.
Gate A	737-300s	CFM56-3C1	0.00	0.00	0.00	0.00	0.00	1.00
	737-3T0/3Q8	CFM56-3B1	0.00	0.00	0.00	0.00	0.00	1.00
	737-522	CFM56-3C1	0.00	0.00	0.00	0.50	0.50	0.00
	737-724	CFM56-7B24	0.00	0.00	0.00	0.00	0.00	0.00
	757-224/224ET	RB211-535E4B	0.00	0.00	0.00	0.00	0.00	0.00
	BH1900C-1/1900D	PT6A-65B	0.00	0.00	0.00	0.50	0.50	0.00
	Cessna 402C II	TSIC-520-VB	0.00	0.00	0.00	0.25	0.75	0.50
	DC-9-14/15	JT8D-7B	0.00	0.00	1.00	0.00	0.00	0.00
	MD-81/82/83	JT8D-217A	0.00	0.00	1.00	1.00	1.00	0.50
	MD-81/82/88	JT8D-217C	0.00	0.00	0.00	0.00	0.00	0.00
	RJ145LR	AE3007A1/2	0.00	0.00	1.00	0.00	0.00	0.00
Gate B	727-225/227/254	JT8D-7B	0.00	0.00	1.00	1.00	1.00	1.00
	737-200s	JT8D-15	0.00	0.00	0.00	1.00	0.00	0.25
	737-200s	JT8D-17	0.00	0.00	0.00	0.00	0.00	1.00
	737-301/3B7	CFM56-3B2	0.00	0.00	0.50	0.33	1.00	0.67
	737-401/4B7	CFM56-3B2	0.00	0.00	0.00	1.00	0.50	0.00
	737-823	CFM56-7B26	0.00	0.00	1.00	1.00	1.00	0.00
	757-223	RB211-535E4-B	0.00	0.00	0.00	0.00	1.00	0.00
	757-225/2B7 (US)	RB211-535E4	0.00	0.00	1.00	0.33	0.33	0.00
	767-223	CF6-80C2B6	0.00	0.00	0.00	0.00	0.00	0.00
	767-323ER	CF6-80C2B6	0.00	0.00	0.00	0.00	0.00	1.00
	A300-605R	CF6-80C2A5	0.00	0.00	1.00	1.00	0.00	0.00
	A319-132	V2524-A5	0.00	0.00	0.00	0.00	0.00	0.00
	A320-211	CFM56-5A1	0.00	0.00	0.00	0.00	1.00	0.00
	A320-232 (HP)	V2527-A5	0.00	0.00	1.00	0.00	0.00	0.00
	ATR 42-300	PW120	0.00	0.00	0.50	0.00	0.00	0.00
	BH1900D	PT6A-67D	0.00	0.00	0.17	0.83	0.50	0.50
	CR Jet 200ER	CF34-3B1	0.00	0.00	0.00	0.00	0.00	0.00
	DC-9-31/32	JT8D-7B	0.00	0.00	0.50	0.50	0.00	0.00
	DHC-8-102 Dash 8	PW120A	0.00	0.00	0.00	0.00	0.50	1.00
	F28 Fellowship 1000	Spey 555-15N	0.00	0.00	1.00	0.00	0.00	0.00
	Fokker 100	Tay 650-15	0.00	0.00	1.00	0.50	0.00	0.50
	MD-80 Luxuary Jet	JT8D-217A	0.00	0.00	0.50	0.50	1.00	0.50

	Aircraft model	Engine model	10-10:59A.M.	11-11:59A.M.	12-12:59P.M.	1-1:59P.M.	2-2:59P.M.	3-3:59P.M.
Gate A	737-300s	CFM56-3C1	0.00	0.00	0.00	0.00	0.00	0.00
	737-3T0/3Q8	CFM56-3B1	1.00	0.00	0.00	1.00	0.00	0.00
	737-522	CFM56-3C1	0.50	0.50	0.00	1.00	1.00	0.00
	737-724	CFM56-7B24	0.00	0.00	0.00	0.00	0.00	0.00
	757-224/224ET	RB211-535E4B	0.00	0.00	1.00	0.00	0.00	0.00
	BH1900C-1/1900D	PT6A-65B	0.50	0.00	0.50	0.00	1.00	0.00
	Cessna 402C II	TSIC-520-VB	1.00	0.25	1.00	0.50	0.75	0.50
	DC-9-14/15	JT8D-7B	0.00	0.00	0.00	0.00	0.00	0.00
	MD-81/82/83	JT8D-217A	0.50	0.50	0.00	0.50	0.50	0.50
	MD-81/82/88	JT8D-217C	0.00	1.00	0.00	1.00	0.00	0.00
	RJ145LR	AE3007A1/2	0.00	1.00	0.00	0.00	0.00	0.00
Gate B	727-225/227/254	JT8D-7B	1.00	1.00	1.00	1.00	1.00	1.00
	737-200s	JT8D-15	0.50	0.50	0.00	0.25	0.50	0.00
	737-200s	JT8D-17	0.00	0.00	0.00	0.00	0.00	0.00
	737-301/3B7	CFM56-3B2	0.67	0.33	0.33	0.50	0.33	0.50
	737-401/4B7	CFM56-3B2	0.00	0.00	1.00	0.00	0.00	0.50
	737-823	CFM56-7B26	0.00	0.00	1.00	0.00	0.00	0.00
	757-223	RB211-535E4-B	0.00	0.33	0.33	0.00	0.00	0.33
	757-225/2B7 (US)	RB211-535E4	0.33	0.00	0.33	0.00	0.00	0.33
	767-223	CF6-80C2B6	0.00	0.50	0.00	0.00	0.00	0.50
	767-323ER	CF6-80C2B6	0.00	0.00	0.00	0.00	0.00	0.00
	A300-605R	CF6-80C2A5	0.00	0.00	1.00	0.00	0.00	0.00
	A319-132	V2524-A5	0.00	1.00	0.00	0.00	0.00	0.00
	A320-211	CFM56-5A1	0.00	0.00	0.00	0.00	0.00	0.00
	A320-232 (HP)	V2527-A5	0.00	0.00	0.50	0.00	0.50	0.00
	ATR 42-300	PW120	1.00	0.50	0.00	0.00	0.00	0.00
	BH1900D	PT6A-67D	0.17	0.83	0.67	0.00	1.00	0.33
	CR Jet 200ER	CF34-3B1	0.00	0.00	0.00	0.00	0.00	1.00
	DC-9-31/32	JT8D-7B	0.00	0.50	0.50	0.50	0.00	0.00
	DHC-8-102 Dash 8	PW120A	0.00	1.00	0.50	1.00	0.00	0.00
	F28 Fellowship 1000	Spey 555-15N	0.00	0.00	0.00	0.00	1.00	0.00
	Fokker 100	Tay 650-15	0.00	0.50	0.50	0.00	0.00	0.50
	MD-80 Luxuary Jet	JT8D-217A	0.50	0.50	0.00	1.00	1.00	0.50

	Aircraft model	Engine model	4-4:59P.M.	5-5:59P.M.	6-6:59P.M.	7-7:59P.M.	8-8:59P.M.	9-9:59P.M.
Gate A	737-300s	CFM56-3C1	0.00	1.00	0.00	0.00	0.00	0.00
	737-3T0/3Q8	CFM56-3B1	1.00	0.00	1.00	1.00	0.00	0.00
	737-522	CFM56-3C1	0.50	0.00	1.00	0.50	0.00	0.00
	737-724	CFM56-7B24	1.00	0.00	0.00	0.00	0.00	0.00
	757-224/224ET	RB211-535E4B	0.00	0.00	0.00	0.00	0.00	0.00
	BH1900C-1/1900D	PT6A-65B	0.00	0.50	0.00	0.50	0.00	0.00
	Cessna 402C II	TSIC-520-VB	0.75	0.75	0.75	0.75	0.75	0.00
	DC-9-14/15	JT8D-7B	0.00	0.00	0.00	0.00	0.00	0.00
	MD-81/82/83	JT8D-217A	0.50	0.50	0.50	0.50	0.50	0.00
	MD-81/82/88	JT8D-217C	0.00	0.00	0.00	1.00	0.00	0.00
	RJ145LR	AE3007A1/2	0.00	0.00	1.00	0.00	0.00	0.00
Gate B	727-225/227/254	JT8D-7B	1.00	1.00	1.00	1.00	1.00	1.00
	737-200s	JT8D-15	0.00	0.50	0.75	0.25	0.00	0.00
	737-200s	JT8D-17	0.00	0.00	0.00	0.00	0.00	0.00
	737-301/3B7	CFM56-3B2	0.50	0.50	0.50	0.67	0.67	0.00
	737-401/4B7	CFM56-3B2	1.00	0.50	0.00	0.00	0.00	0.00
	737-823	CFM56-7B26	0.00	0.00	0.00	1.00	0.00	0.00
	757-223	RB211-535E4-B	0.33	0.00	0.33	0.00	0.00	0.00
	757-225/2B7 (US)	RB211-535E4	0.00	0.00	0.67	0.00	0.00	0.00
	767-223	CF6-80C2B6	0.00	1.00	0.00	0.00	0.00	0.00
	767-323ER	CF6-80C2B6	0.00	0.00	0.00	0.00	0.00	0.00
	A300-605R	CF6-80C2A5	0.00	0.00	1.00	0.00	0.00	0.00
	A319-132	V2524-A5	0.00	0.00	1.00	0.00	0.00	0.00
	A320-211	CFM56-5A1	0.00	0.00	0.00	0.00	0.00	0.00
	A320-232 (HP)	V2527-A5	0.00	0.50	0.00	0.00	0.00	0.00
	ATR 42-300	PW120	0.00	0.00	0.50	0.50	0.00	0.00
	BH1900D	PT6A-67D	0.67	0.50	0.83	0.67	0.50	0.33
	CR Jet 200ER	CF34-3B1	0.00	0.00	0.00	0.00	0.00	0.00
	DC-9-31/32	JT8D-7B	0.00	0.00	0.50	1.00	0.50	0.00
	DHC-8-102 Dash 8	PW120A	1.00	0.50	0.00	1.00	1.00	0.00
	F28 Fellowship 1000	Spey 555-15N	0.00	0.00	1.00	0.00	0.00	0.00
	Fokker 100	Tay 650-15	0.00	0.50	0.50	0.50	0.50	0.00
	MD-80 Luxuary Jet	JT8D-217A	1.00	0.50	0.50	1.00	0.00	0.00

	Aircraft model	Engine model	10-10:59P.M.	11-11:59P.M.
Gate A	737-300s	CFM56-3C1	0.00	0.00
	737-3T0/3Q8	CFM56-3B1	0.00	0.00
	737-522	CFM56-3C1	0.00	0.00
	737-724	CFM56-7B24	0.00	0.00
	757-224/224ET	RB211-535E4B	0.00	0.00
	BH1900C-1/1900D	PT6A-65B	0.00	0.00
	Cessna 402C II	TSIC-520-VB	0.00	0.00
	DC-9-14/15	JT8D-7B	0.00	0.00
	MD-81/82/83	JT8D-217A	0.00	0.00
	MD-81/82/88	JT8D-217C	0.00	0.00
	RJ145LR	AE3007A1/2	0.00	0.00
Gate B	727-225/227/254	JT8D-7B	1.00	0.00
	737-200s	JT8D-15	0.00	0.00
	737-200s	JT8D-17	0.00	0.00
	737-301/3B7	CFM56-3B2	0.00	0.00
	737-401/4B7	CFM56-3B2	0.00	0.00
	737-823	CFM56-7B26	0.00	0.00
	757-223	RB211-535E4-B	0.00	0.00
	757-225/2B7 (US)	RB211-535E4	0.00	0.00
	767-223	CF6-80C2B6	0.00	0.00
	767-323ER	CF6-80C2B6	0.00	0.00
	A300-605R	CF6-80C2A5	0.00	0.00
	A319-132	V2524-A5	0.00	0.00
	A320-211	CFM56-5A1	0.00	0.00
	A320-232 (HP)	V2527-A5	0.00	0.00
	ATR 42-300	PW120	0.00	0.00
	BH1900D	PT6A-67D	0.00	0.00
	CR Jet 200ER	CF34-3B1	0.00	0.00
	DC-9-31/32	JT8D-7B	0.00	0.00
	DHC-8-102 Dash 8	PW120A	0.00	0.00
	F28 Fellowship 1000	Spey 555-15N	0.00	0.00
	Fokker 100	Tay 650-15	0.00	0.00
	MD-80 Luxuary Jet	JT8D-217A	0.00	0.00

	Aircraft model	Engine model	Number of Departures Peak hour	Daily total	12-12:59A.M.	1-1:59A.M.	2-2:59A.M.	3-3:59A.M.
Gate B *(cont'd)*	MD-81/82	JT8D-217	2	6	0.00	0.00	0.00	0.00
	SF 340B	CT7-9B	1	4	0.00	0.00	0.00	0.00
Gate C	727-200s	JT8D-15	4	28	0.00	0.00	0.00	0.00
	737-200s	JT8D-15A	2	15	0.00	0.00	0.00	0.00
	737-322	CFM56-3B1	1	7	0.00	0.00	0.00	0.00
	737-524	CFM56-3C1	1	3	0.00	0.00	0.00	0.00
	757-200s	PW2037	4	28	0.00	0.00	0.00	0.00
	767-200s/300s/400s	PW4060	3	7	0.00	0.00	0.00	0.00
	767-222/222ET	JT9D-7R4D	1	4	0.00	0.00	0.00	0.00
	A319-131	V2522-A5	1	2	0.00	0.00	0.00	0.00
	A320-232	V2527-A5	2	6	0.00	0.00	0.00	0.00
	BAE Jetstream 32	TPE331-12UAR-701H	1	1	0.00	0.00	0.00	0.00
	BAE Jetstream 41	TPE331-14HR-805H	2	17	0.00	0.00	0.00	0.00
	CL-601s/604	CF34-3A	2	7	0.00	0.00	0.00	0.00
	L-1011-351/351-15	RB211-524B4	1	3	0.00	0.00	0.00	0.00
	MD-82/83	JT8D-219	1	6	0.00	0.00	0.00	0.00
	MD-88	JT8D-219	1	4	0.00	0.00	0.00	0.00
	RJ145ER	AE3007A	2	6	0.00	0.00	0.00	0.00
	SF340A/340B	CT7-5A2	10	110	0.00	0.00	0.00	0.00
Gate D	727s	JT8D-7B	1	1	0.00	0.00	0.00	0.00
	DC-9-31/32	JT8D-7B	1	5	0.00	0.00	0.00	0.00
Gate E	727-200s	JT8D-17R	1	1	0.00	0.00	0.00	0.00
	727-200s (NW)	JT8D-15	1	3	0.00	0.00	0.00	0.00
	747-136/236B/436	RB211-524H2	1	2	0.00	0.00	0.00	0.00
	747-200s/400s	RB211-524D4	1	1	0.00	0.00	0.00	0.00
	747-357	JT9D-7R4G2	1	1	0.00	0.00	0.00	0.00
	747-400s	PW4056	1	1	0.00	0.00	0.00	0.00
	757-200s/308	RB211-535E4	1	1	0.00	0.00	0.00	0.00
	757-251	PW2037	2	8	0.00	0.00	0.00	0.00
	767-33A(ER)/36M(ER)	CF6-80C2B6F	1	1	0.00	0.00	0.00	0.00
	777-236/236ER	GE90-85B	1	1	0.00	0.00	0.00	0.00

	Aircraft model	Engine model	4-4:59A.M.	5-5:59A.M.	6-6:59A.M.	7-7:59A.M.	8-8:59A.M.	9-9:59A.M.
Gate B *(cont'd)*	MD-81/82	JT8D-217	0.00	0.00	1.00	0.00	0.50	0.00
	SF 340B	CT7-9B	0.00	0.00	0.00	0.00	0.00	0.00
Gate C	727-200s	JT8D-15	0.00	0.00	0.50	0.25	0.50	0.25
	737-200s	JT8D-15A	0.00	0.00	0.00	1.00	0.50	0.50
	737-322	CFM56-3B1	0.00	0.00	1.00	1.00	0.00	1.00
	737-524	CFM56-3C1	0.00	1.00	0.00	1.00	0.00	0.00
	757-200s	PW2037	0.00	0.25	0.75	0.25	0.75	0.50
	767-200s/300s/400s	PW4060	0.00	0.00	0.00	0.00	0.00	1.00
	767-222/222ET	JT9D-7R4D	0.00	0.00	0.00	0.00	1.00	0.00
	A319-131	V2522-A5	0.00	0.00	1.00	0.00	0.00	0.00
	A320-232	V2527-A5	0.00	0.00	0.50	0.00	0.50	0.00
	BAE Jetstream 32	TPE331-12UAR-701H	0.00	0.00	0.00	0.00	0.00	0.00
	BAE Jetstream 41	TPE331-14HR-805H	0.00	0.50	1.00	0.00	0.50	0.50
	CL-601s/604	CF34-3A	0.00	0.00	1.00	0.00	0.00	0.00
	L-1011-351/351-15	RB211-524B4	0.00	0.00	0.00	0.00	1.00	0.00
	MD-82/83	JT8D-219	0.00	0.00	1.00	0.00	0.00	0.00
	MD-88	JT8D-219	0.00	0.00	0.00	1.00	0.00	0.00
	RJ145ER	AE3007A	0.00	0.00	0.00	0.50	0.00	0.50
	SF340A/340B	CT7-5A2	0.00	0.00	0.20	0.60	1.00	0.70
Gate D	727s	JT8D-7B	0.00	0.00	0.00	0.00	0.00	0.00
	DC-9-31/32	JT8D-7B	0.00	0.00	1.00	0.00	0.00	1.00
Gate E	727-200s	JT8D-17R	0.00	0.00	0.00	0.00	0.00	0.00
	727-200s (NW)	JT8D-15	0.00	0.00	0.00	0.00	0.00	0.00
	747-136/236B/436	RB211-524H2	0.00	0.00	0.00	0.00	0.00	0.00
	747-200s/400s	RB211-524D4	0.00	0.00	0.00	0.00	0.00	0.00
	747-357	JT9D-7R4G2	0.00	0.00	0.00	0.00	0.00	0.00
	747-400s	PW4056	0.00	0.00	0.00	0.00	0.00	0.00
	757-200s/308	RB211-535E4	0.00	0.00	0.00	0.00	0.00	0.00
	757-251	PW2037	0.00	0.00	0.50	0.50	1.00	0.00
	767-33A(ER)/36M(ER)	CF6-80C2B6F	0.00	0.00	0.00	0.00	0.00	0.00
	777-236/236ER	GE90-85B	0.00	0.00	0.00	0.00	1.00	0.00

	Aircraft model	Engine model	10-10:59A.M.	11-11:59A.M.	12-12:59P.M.	1-1:59P.M.	2-2:59P.M.	3-3:59P.M.
Gate B ***(cont'd)***	MD-81/82	JT8D-217	0.00	0.00	0.00	0.50	0.00	0.00
	SF 340B	CT7-9B	0.00	0.00	0.00	1.00	1.00	1.00
Gate C	727-200s	JT8D-15	0.50	0.50	0.25	0.25	0.75	0.25
	737-200s	JT8D-15A	1.00	0.50	0.00	0.00	0.50	1.00
	737-322	CFM56-3B1	1.00	0.00	1.00	0.00	0.00	1.00
	737-524	CFM56-3C1	0.00	0.00	0.00	0.00	0.00	1.00
	757-200s	PW2037	0.50	0.25	0.25	0.50	0.75	0.00
	767-200s/300s/400s	PW4060	0.00	0.00	0.00	0.00	0.00	0.33
	767-222/222ET	JT9D-7R4D	0.00	1.00	0.00	0.00	0.00	0.00
	A319-131	V2522-A5	0.00	0.00	1.00	0.00	0.00	0.00
	A320-232	V2527-A5	0.00	1.00	0.00	0.00	0.00	0.50
	BAE Jetstream 32	TPE331-12UAR-701H	1.00	0.00	0.00	0.00	0.00	0.00
	BAE Jetstream 41	TPE331-14HR-805H	1.00	0.50	1.00	0.50	0.00	0.50
	CL-601s/604	CF34-3A	0.50	0.00	0.50	0.00	0.50	0.00
	L-1011-351/351-15	RB211-524B4	0.00	0.00	1.00	0.00	0.00	1.00
	MD-82/83	JT8D-219	0.00	1.00	0.00	1.00	1.00	0.00
	MD-88	JT8D-219	0.00	0.00	0.00	1.00	0.00	0.00
	RJ145ER	AE3007A	0.00	0.00	1.00	0.00	0.50	0.00
	SF340A/340B	CT7-5A2	0.50	0.80	0.70	0.70	0.90	0.80
Gate D	727s	JT8D-7B	0.00	0.00	0.00	0.00	0.00	0.00
	DC-9-31/32	JT8D-7B	0.00	0.00	0.00	0.00	1.00	0.00
Gate E	727-200s	JT8D-17R	0.00	1.00	0.00	0.00	0.00	0.00
	727-200s (NW)	JT8D-15	1.00	1.00	0.00	1.00	0.00	0.00
	747-136/236B/436	RB211-524H2	0.00	0.00	0.00	0.00	0.00	0.00
	747-200s/400s	RB211-524D4	0.00	0.00	0.00	0.00	0.00	0.00
	747-357	JT9D-7R4G2	0.00	0.00	0.00	0.00	0.00	0.00
	747-400s	PW4056	0.00	0.00	0.00	0.00	0.00	0.00
	757-200s/308	RB211-535E4	0.00	0.00	0.00	0.00	0.00	0.00
	757-251	PW2037	0.00	0.00	0.50	0.50	0.00	0.50
	767-33A(ER)/36M(ER)	CF6-80C2B6F	0.00	0.00	0.00	0.00	0.00	0.00
	777-236/236ER	GE90-85B	0.00	0.00	0.00	0.00	0.00	0.00

	Aircraft model	Engine model	4-4:59P.M.	5-5:59P.M.	6-6:59P.M.	7-7:59P.M.	8-8:59P.M.	9-9:59P.M.
Gate B *(cont'd)*	MD-81/82	JT8D-217	0.50	0.00	0.00	0.00	0.50	0.00
	SF 340B	CT7-9B	1.00	0.00	0.00	0.00	0.00	0.00
Gate C	727-200s	JT8D-15	1.00	0.25	0.25	0.75	0.50	0.25
	737-200s	JT8D-15A	0.00	0.50	1.00	0.50	0.50	0.00
	737-322	CFM56-3B1	0.00	1.00	0.00	0.00	0.00	0.00
	737-524	CFM56-3C1	0.00	0.00	0.00	0.00	0.00	0.00
	757-200s	PW2037	0.25	1.00	0.25	0.50	0.25	0.00
	767-200s/300s/400s	PW4060	0.00	0.67	0.00	0.00	0.00	0.00
	767-222/222ET	JT9D-7R4D	0.00	1.00	1.00	0.00	0.00	0.00
	A319-131	V2522-A5	0.00	0.00	0.00	0.00	0.00	0.00
	A320-232	V2527-A5	0.00	0.00	0.00	0.00	0.50	0.00
	BAE Jetstream 32	TPE331-12UAR-701H	0.00	0.00	0.00	0.00	0.00	0.00
	BAE Jetstream 41	TPE331-14HR-805H	0.50	1.00	0.00	0.50	0.50	0.00
	CL-601s/604	CF34-3A	0.00	0.50	0.50	0.00	0.00	0.00
	L-1011-351/351-15	RB211-524B4	0.00	0.00	0.00	0.00	0.00	0.00
	MD-82/83	JT8D-219	0.00	1.00	0.00	1.00	0.00	0.00
	MD-88	JT8D-219	1.00	0.00	1.00	0.00	0.00	0.00
	RJ145ER	AE3007A	0.00	0.00	0.00	0.00	0.50	0.00
	SF340A/340B	CT7-5A2	0.70	0.70	0.80	0.80	0.60	0.40
Gate D	727s	JT8D-7B	0.00	0.00	0.00	0.00	0.00	0.00
	DC-9-31/32	JT8D-7B	0.00	1.00	0.00	1.00	0.00	0.00
Gate E	727-200s	JT8D-17R	0.00	0.00	0.00	0.00	0.00	0.00
	727-200s (NW)	JT8D-15	0.00	0.00	0.00	0.00	0.00	0.00
	747-136/236B/436	RB211-524H2	0.00	1.00	0.00	0.00	1.00	0.00
	747-200s/400s	RB211-524D4	0.00	0.00	0.00	0.00	1.00	0.00
	747-357	JT9D-7R4G2	0.00	0.00	0.00	1.00	0.00	0.00
	747-400s	PW4056	0.00	0.00	0.00	0.00	0.00	0.00
	757-200s/308	RB211-535E4	0.00	0.00	0.00	0.00	0.00	1.00
	757-251	PW2037	0.00	0.00	0.00	0.50	0.00	0.00
	767-33A(ER)/36M(ER)	CF6-80C2B6F	0.00	0.00	1.00	0.00	0.00	0.00
	777-236/236ER	GE90-85B	0.00	0.00	0.00	0.00	0.00	0.00

	Aircraft model	Engine model	10-10:59P.M.	11-11:59P.M.
Gate B ***(cont'd)***	MD-81/82	JT8D-217	0.00	0.00
	SF 340B	CT7-9B	0.00	0.00
Gate C	727-200s	JT8D-15	0.00	0.00
	737-200s	JT8D-15A	0.00	0.00
	737-322	CFM56-3B1	0.00	0.00
	737-524	CFM56-3C1	0.00	0.00
	757-200s	PW2037	0.00	0.00
	767-200s/300s/400s	PW4060	0.00	0.33
	767-222/222ET	JT9D-7R4D	0.00	0.00
	A319-131	V2522-A5	0.00	0.00
	A320-232	V2527-A5	0.00	0.00
	BAE Jetstream 32	TPE331-12UAR-701H	0.00	0.00
	BAE Jetstream 41	TPE331-14HR-805H	0.00	0.00
	CL-601s/604	CF34-3A	0.00	0.00
	L-1011-351/351-15	RB211-524B4	0.00	0.00
	MD-82/83	JT8D-219	0.00	0.00
	MD-88	JT8D-219	0.00	0.00
	RJ145ER	AE3007A	0.00	0.00
	SF340A/340B	CT7-5A2	0.10	0.00
Gate D	727s	JT8D-7B	1.00	0.00
	DC-9-31/32	JT8D-7B	0.00	0.00
Gate E	727-200s	JT8D-17R	0.00	0.00
	727-200s (NW)	JT8D-15	0.00	0.00
	747-136/236B/436	RB211-524H2	0.00	0.00
	747-200s/400s	RB211-524D4	0.00	0.00
	747-357	JT9D-7R4G2	0.00	0.00
	747-400s	PW4056	1.00	0.00
	757-200s/308	RB211-535E4	0.00	0.00
	757-251	PW2037	0.00	0.00
	767-33A(ER)/36M(ER)	CF6-80C2B6F	0.00	0.00
	777-236/236ER	GE90-85B	0.00	0.00

	Aircraft model	Engine model	Number of Departures Peak hour	Daily total	12-12:59A.M.	1-1:59A.M.	2-2:59A.M.	3-3:59A.M.
Gate E *(cont'd)*	A310-304	CF6-80C2A2	1	1	0.00	0.00	0.00	0.00
	A319-114	CFM56-5A5	1	7	0.00	0.00	0.00	0.00
	A320-212	CFM56-5A3	1	3	0.00	0.00	0.00	0.00
	A330-301/223/322	PW4168A	1	1	0.00	0.00	0.00	0.00
	A330-301/302	CF6-80E1A2	1	1	0.00	0.00	0.00	0.00
	CR Jet 100ER	CF34-3A1	1	6	0.00	0.00	0.00	0.00
	DC-10-30	CF6-50C	1	2	0.00	0.00	0.00	0.00
	DC-9-31/32/41/51	JT8D-9A	1	1	0.00	0.00	0.00	0.00
	DHC-8-102 Dash 8 (ACs)	PW120A	2	9	0.00	0.00	0.00	0.00

	Aircraft model	Engine model	4-4:59A.M.	5-5:59A.M.	6-6:59A.M.	7-7:59A.M.	8-8:59A.M.	9-9:59A.M.
Gate E *(cont'd)*	A310-304	CF6-80C2A2	0.00	0.00	0.00	0.00	0.00	0.00
	A319-114	CFM56-5A5	0.00	0.00	0.00	1.00	0.00	1.00
	A320-212	CFM56-5A3	0.00	0.00	1.00	0.00	0.00	0.00
	A330-301/223/322	PW4168A	0.00	0.00	0.00	0.00	0.00	0.00
	A330-301/302	CF6-80E1A2	0.00	0.00	0.00	0.00	0.00	0.00
	CR Jet 100ER	CF34-3A1	0.00	0.00	0.00	0.00	1.00	0.00
	DC-10-30	CF6-50C	0.00	0.00	0.00	1.00	0.00	0.00
	DC-9-31/32/41/51	JT8D-9A	0.00	0.00	0.00	0.00	0.00	0.00
	DHC-8-102 Dash 8 (ACs)	PW120A	0.00	0.00	0.00	0.00	0.50	0.50

	Aircraft model	Engine model	10-10:59A.M.	11-11:59A.M.	12-12:59P.M.	1-1:59P.M.	2-2:59P.M.	3-3:59P.M.
Gate E *(cont'd)*	A310-304	CF6-80C2A2	0.00	0.00	0.00	0.00	0.00	0.00
	A319-114	CFM56-5A5	0.00	1.00	0.00	1.00	0.00	1.00
	A320-212	CFM56-5A3	0.00	0.00	0.00	0.00	0.00	0.00
	A330-301/223/322	PW4168A	0.00	0.00	0.00	0.00	0.00	0.00
	A330-301/302	CF6-80E1A2	0.00	0.00	0.00	0.00	0.00	0.00
	CR Jet 100ER	CF34-3A1	1.00	1.00	0.00	0.00	1.00	0.00
	DC-10-30	CF6-50C	0.00	0.00	0.00	0.00	0.00	0.00
	DC-9-31/32/41/51	JT8D-9A	0.00	0.00	0.00	0.00	0.00	0.00
	DHC-8-102 Dash 8 (ACs)	PW120A	0.00	0.00	1.00	0.00	0.00	0.50

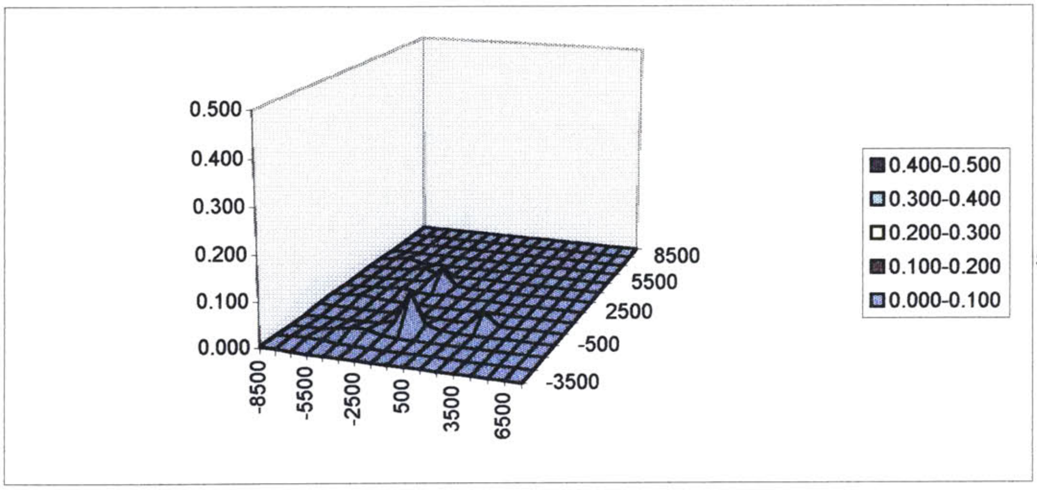
	Aircraft model	Engine model	4-4:59P.M.	5-5:59P.M.	6-6:59P.M.	7-7:59P.M.	8-8:59P.M.	9-9:59P.M.
Gate E *(cont'd)*	A310-304	CF6-80C2A2	0.00	0.00	1.00	0.00	0.00	0.00
	A319-114	CFM56-5A5	0.00	1.00	0.00	1.00	0.00	0.00
	A320-212	CFM56-5A3	0.00	1.00	1.00	0.00	0.00	0.00
	A330-301/223/322	PW4168A	0.00	0.00	0.00	1.00	0.00	0.00
	A330-301/302	CF6-80E1A2	0.00	0.00	0.00	0.00	1.00	0.00
	CR Jet 100ER	CF34-3A1	0.00	1.00	0.00	1.00	0.00	0.00
	DC-10-30	CF6-50C	0.00	1.00	0.00	0.00	0.00	0.00
	DC-9-31/32/41/51	JT8D-9A	1.00	0.00	0.00	0.00	0.00	0.00
	DHC-8-102 Dash 8 (ACs)	PW120A	0.50	0.00	0.50	0.00	1.00	0.00

	Aircraft model	Engine model	10-10:59P.M.	11-11:59P.M.
Gate E *(cont'd)*	A310-304	CF6-80C2A2	0.00	0.00
	A319-114	CFM56-5A5	0.00	0.00
	A320-212	CFM56-5A3	0.00	0.00
	A330-301/223/322	PW4168A	0.00	0.00
	A330-301/302	CF6-80E1A2	0.00	0.00
	CR Jet 100ER	CF34-3A1	0.00	0.00
	DC-10-30	CF6-50C	0.00	0.00
	DC-9-31/32/41/51	JT8D-9A	0.00	0.00
	DHC-8-102 Dash 8 (ACs)	PW120A	0.00	0.00

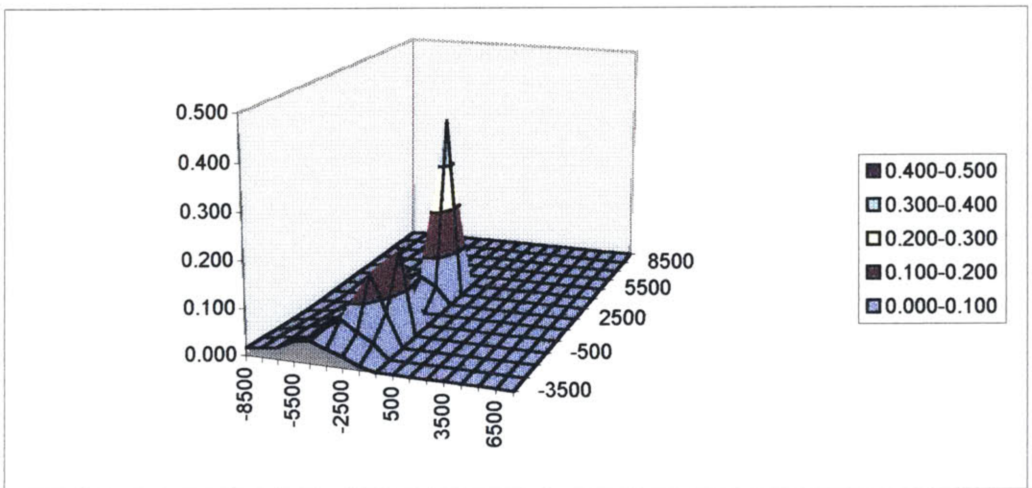
Appendix I

Plots of Pollutant Concentrations Calculated by Dispersion Analysis

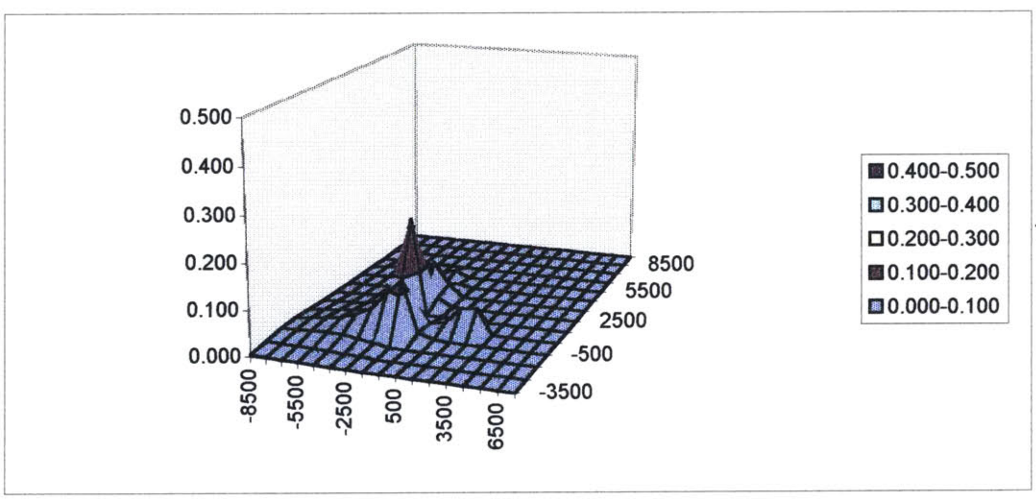
Model day NO_X concentrations



5 A.M.

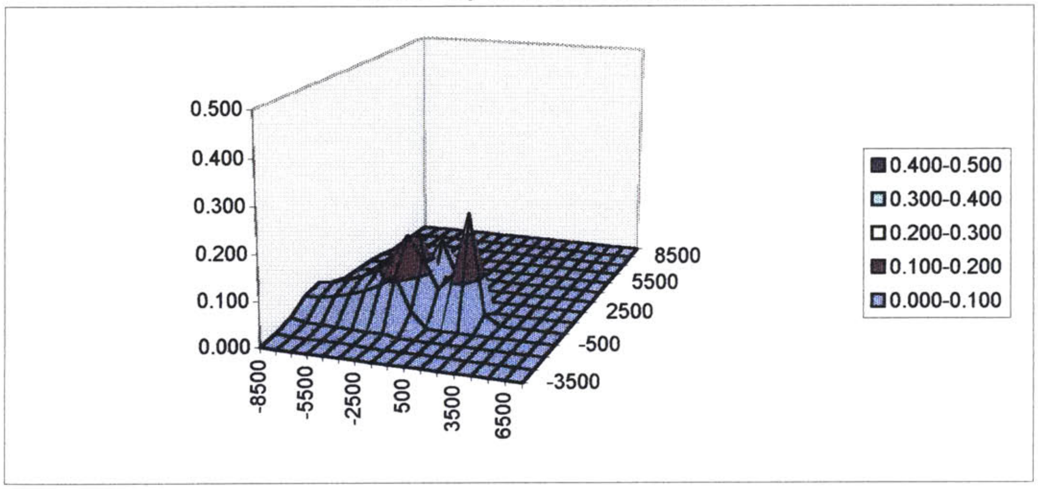


6 A.M.

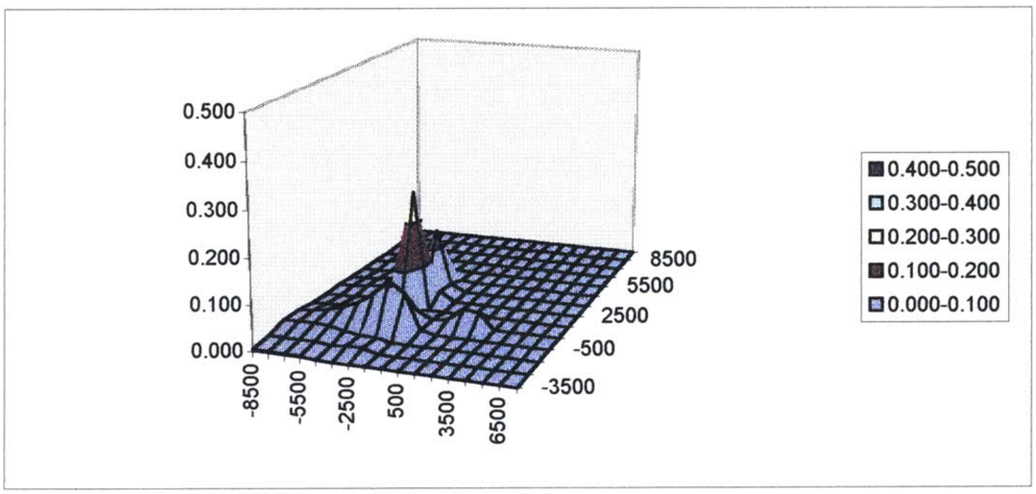


7 A.M.

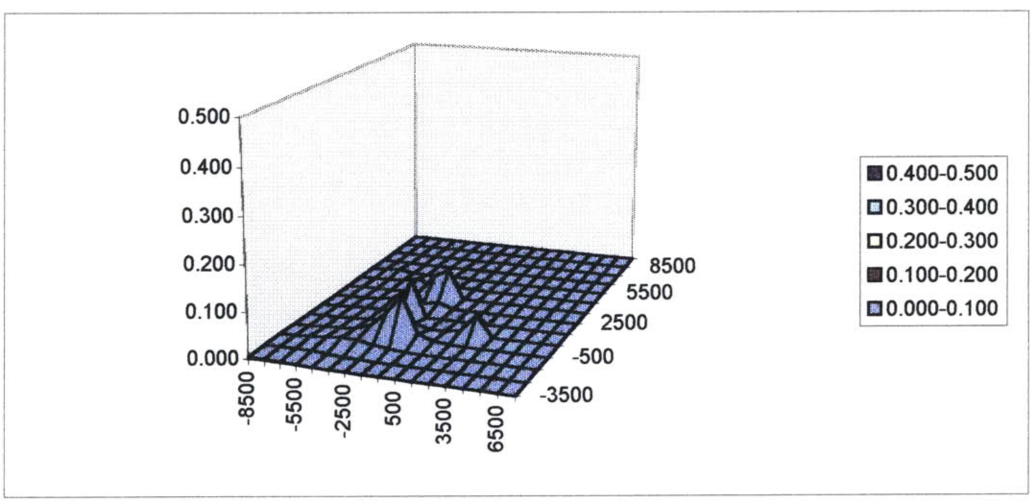
Model day NO_X concentrations



8 A.M.

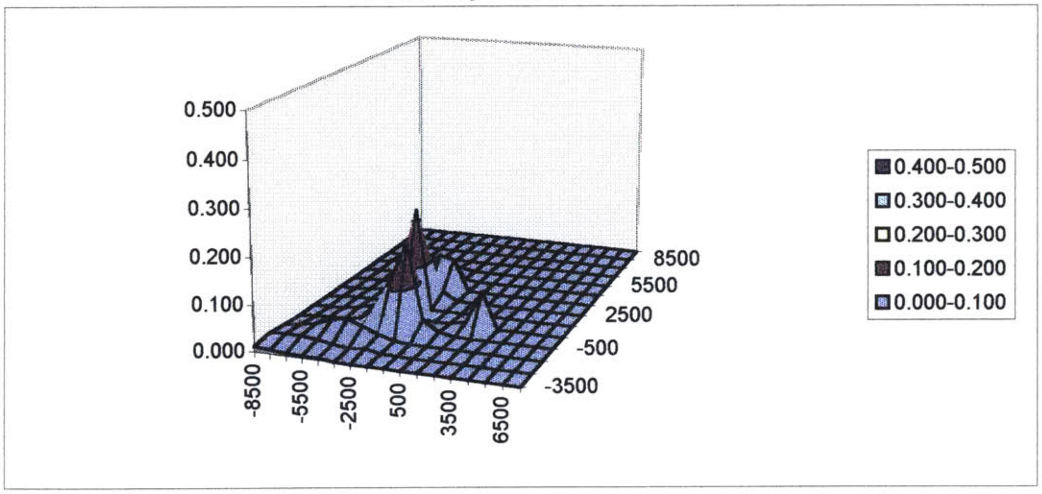


9 A.M.

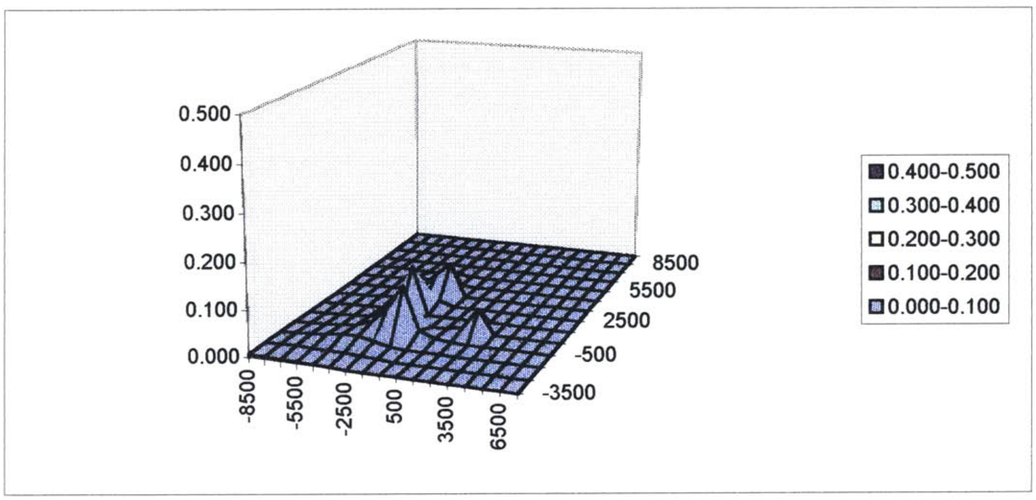


10 A.M.

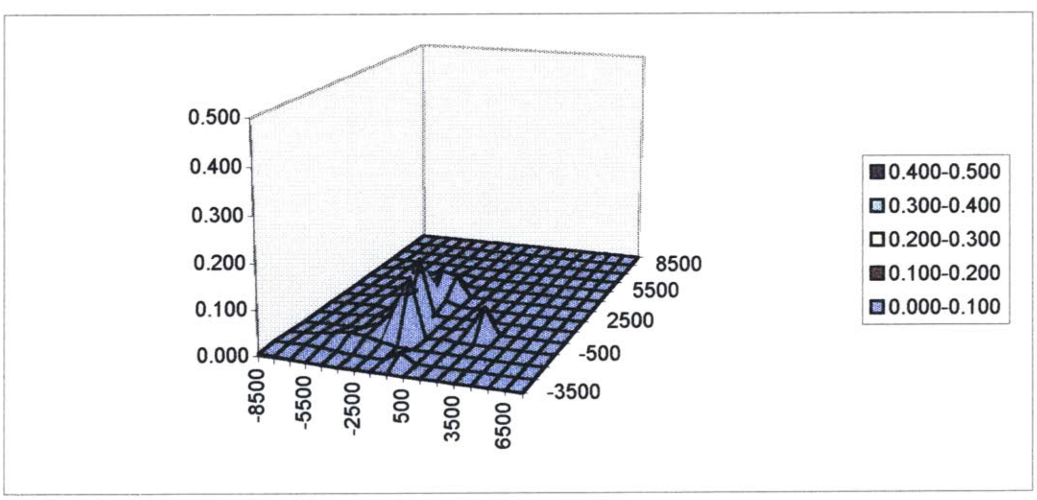
Model day NO_X concentrations



11 A.M.

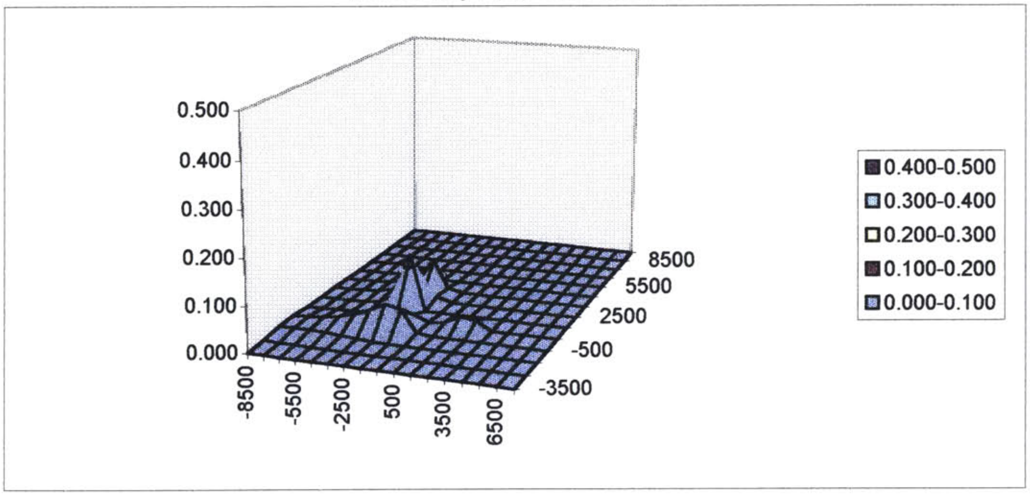


Noon

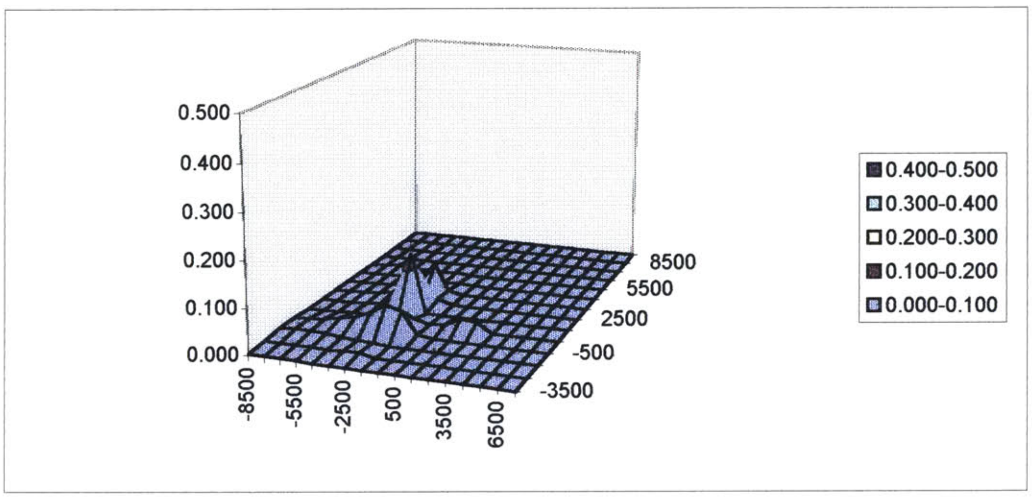


1 P.M.

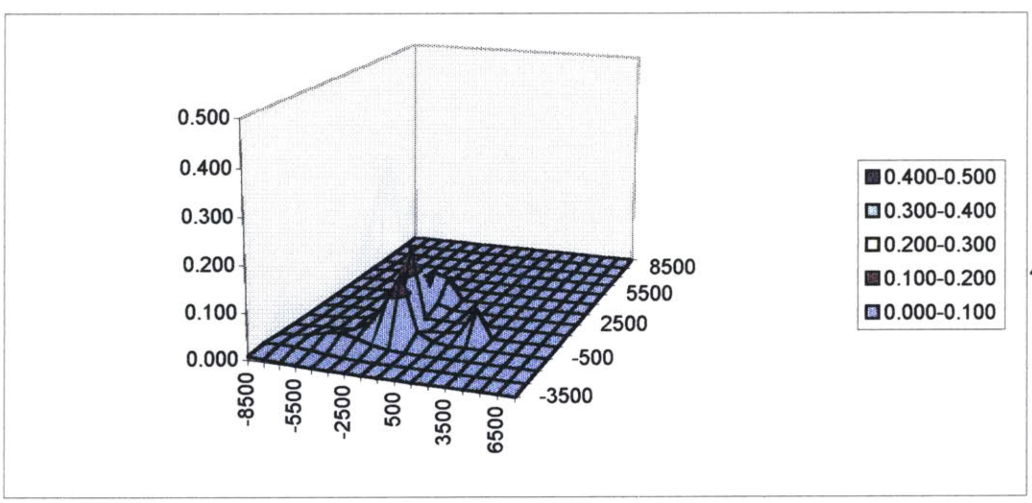
Model day NO_X concentrations



2 P.M.

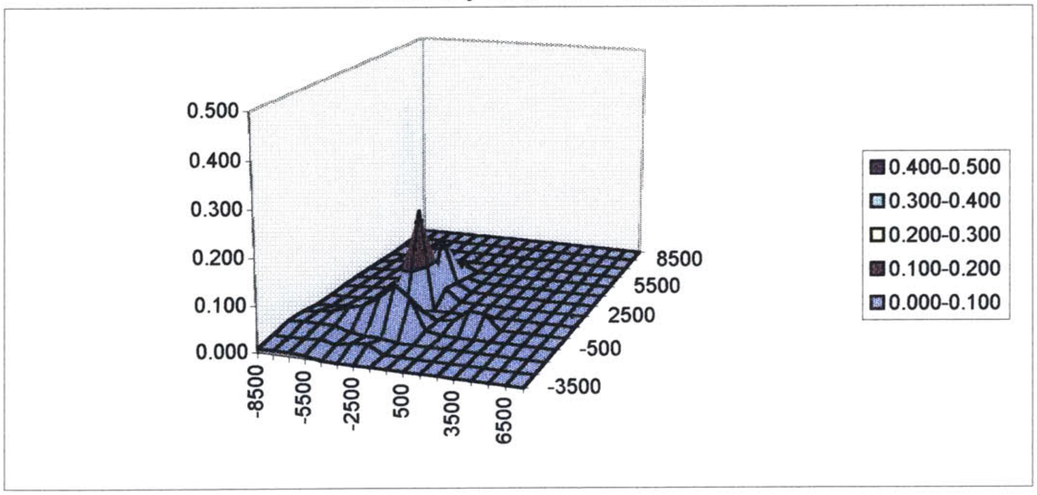


3 P.M.

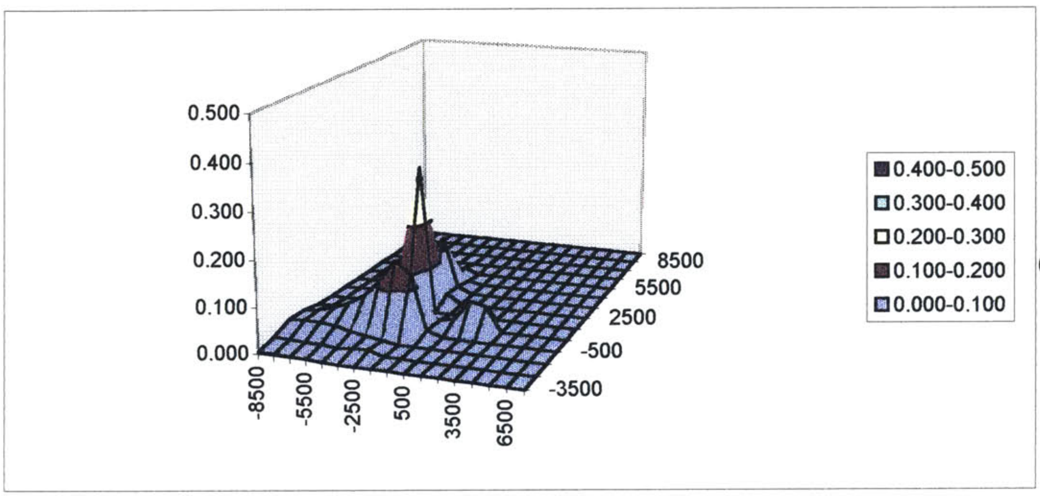


4 P.M.

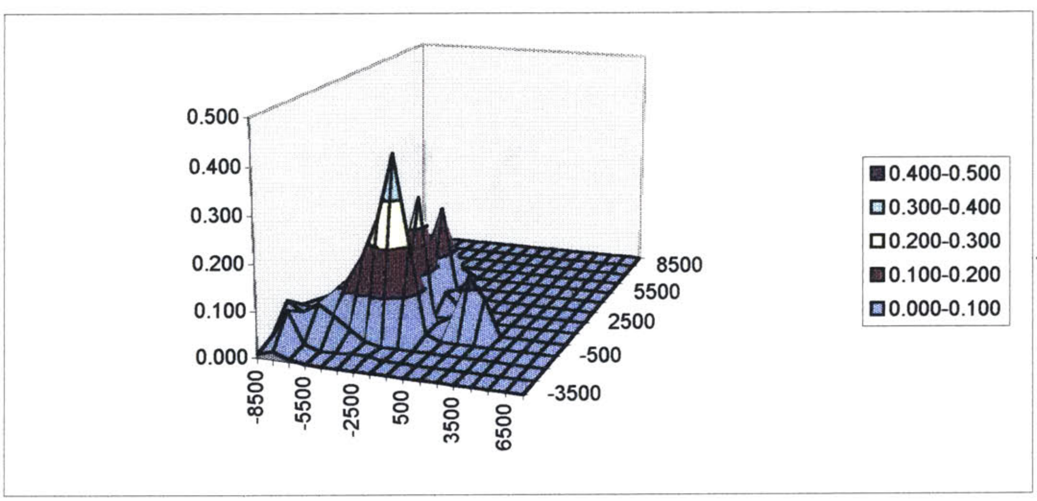
Model day NO_X concentrations



5 P.M.

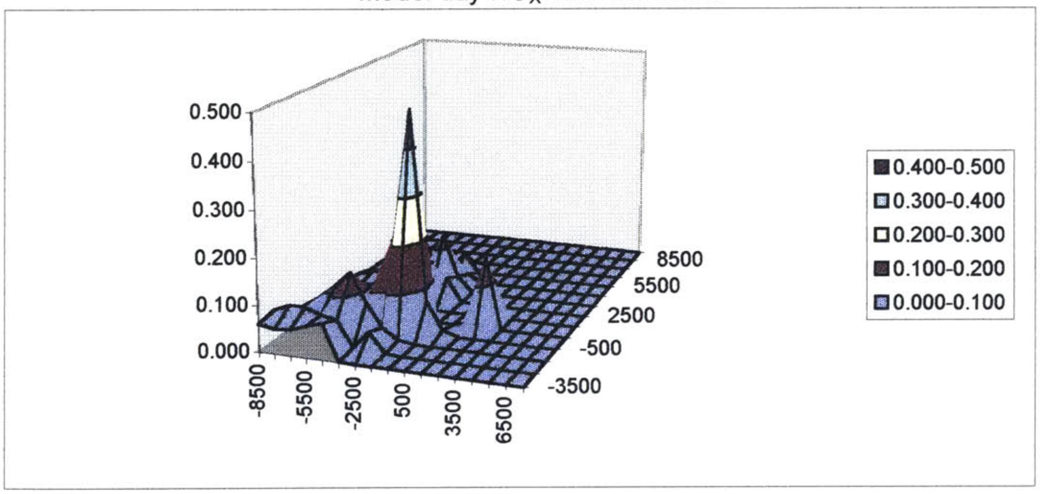


6 P.M.

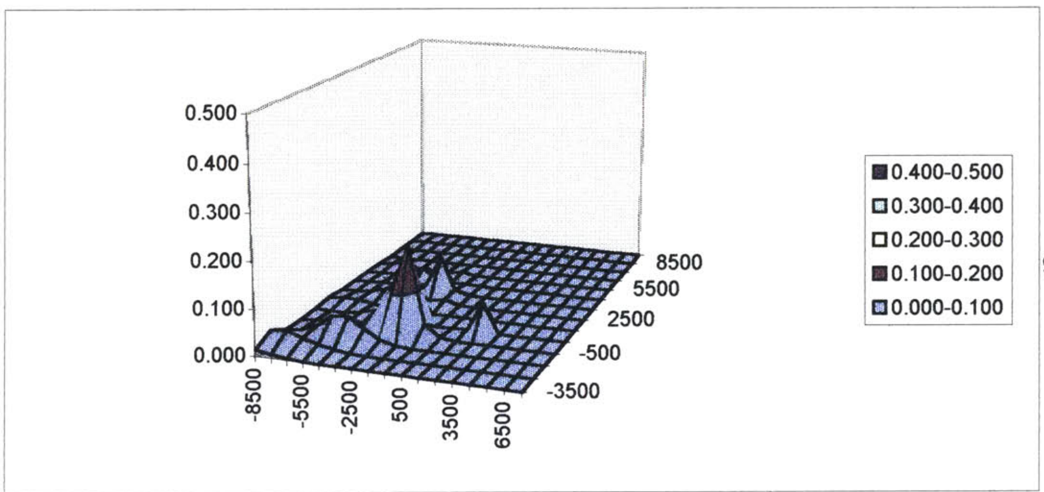


7 P.M.

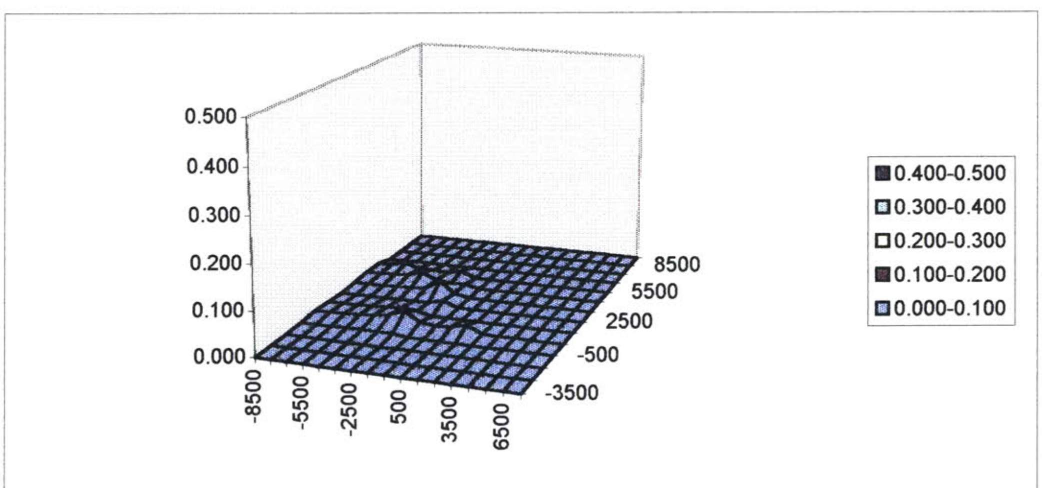
Model day NO_X concentrations



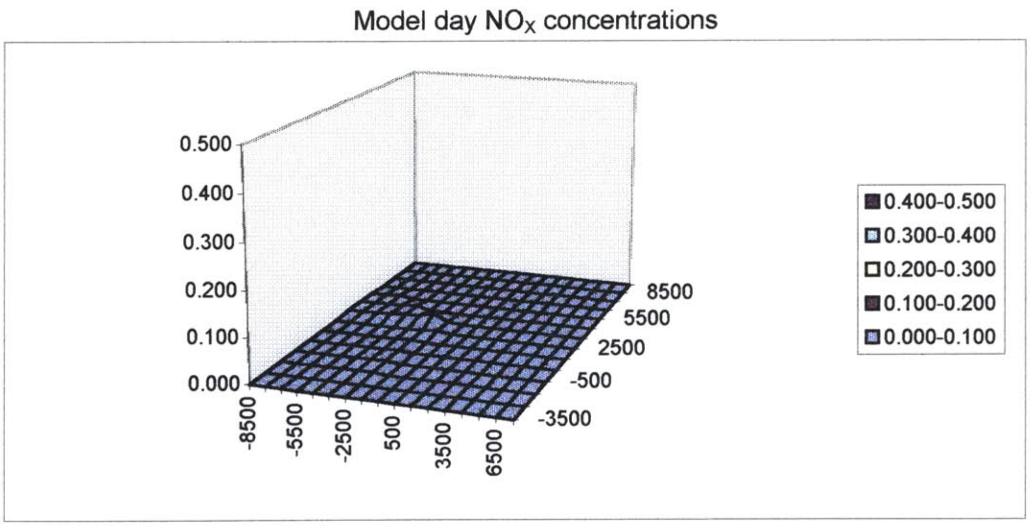
8 P.M.



9 P.M.

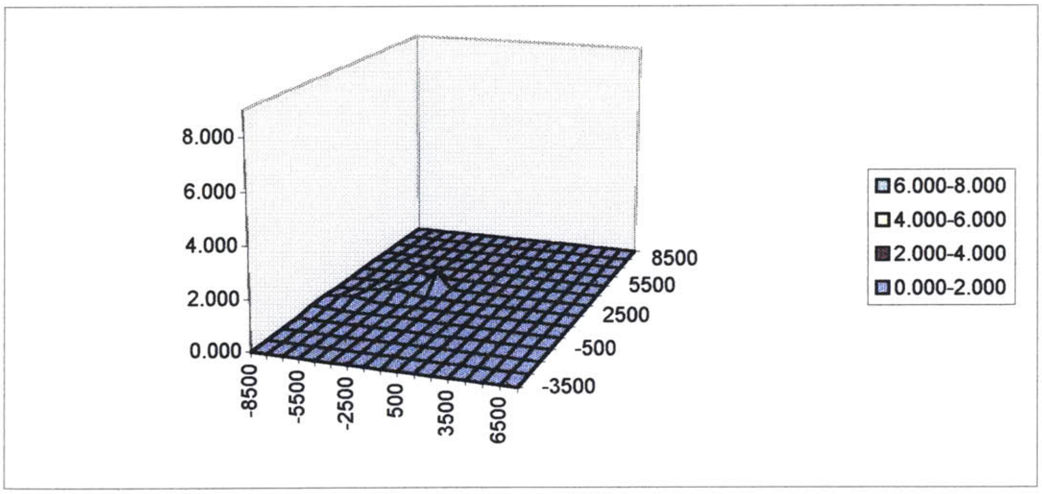


10 P.M.

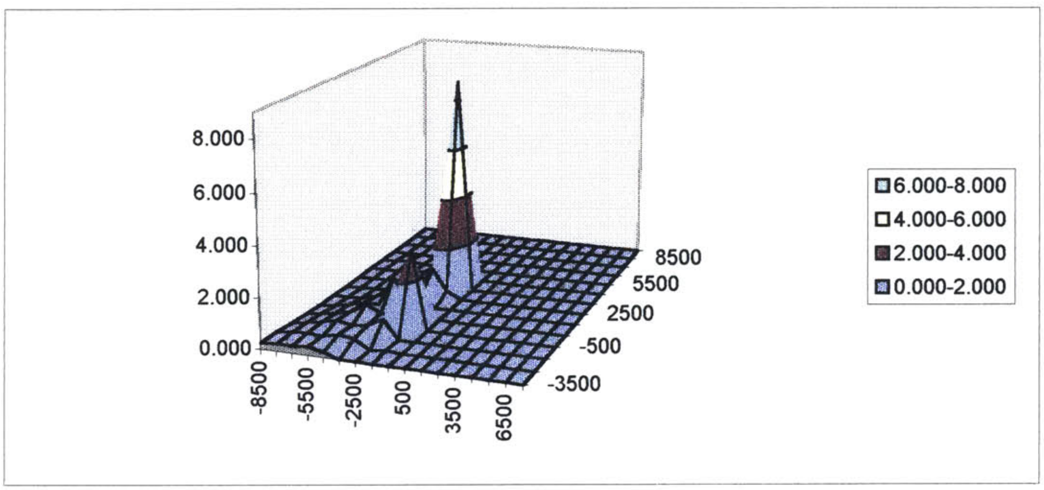

Model day NO_X concentrations
0.500
0.400
0.300
0.200
0.100
0.000
-8500
-5500
-2500
500
3500
6500
8500
5500
2500
-500
-3500
0.400-0.500
0.300-0.400
0.200-0.300
0.100-0.200
0.000-0.100

11 P.M.

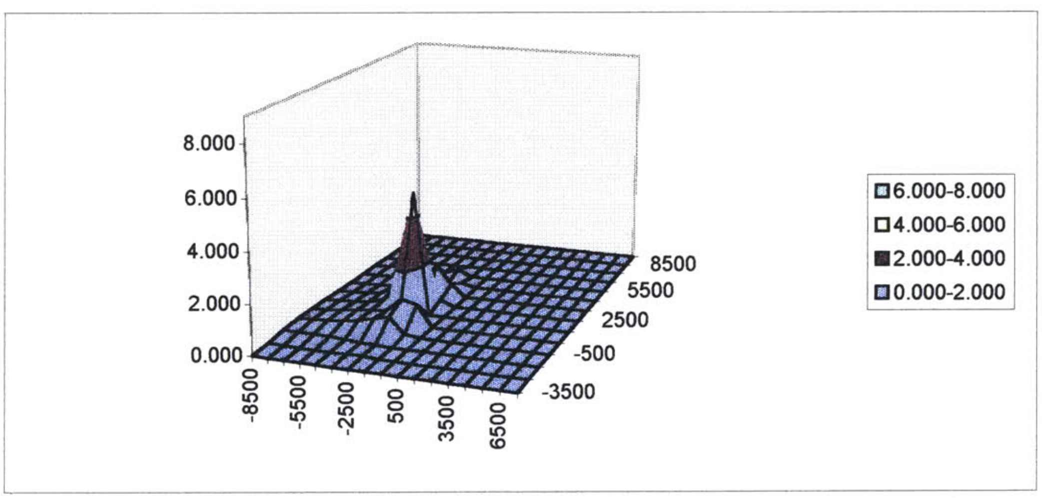
Model day CO concentrations



5 A.M.

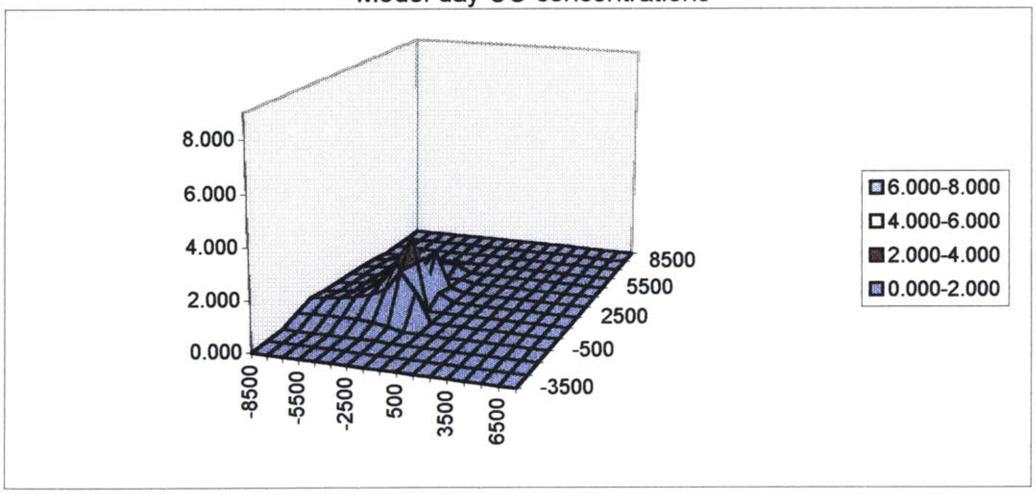


6 A.M.

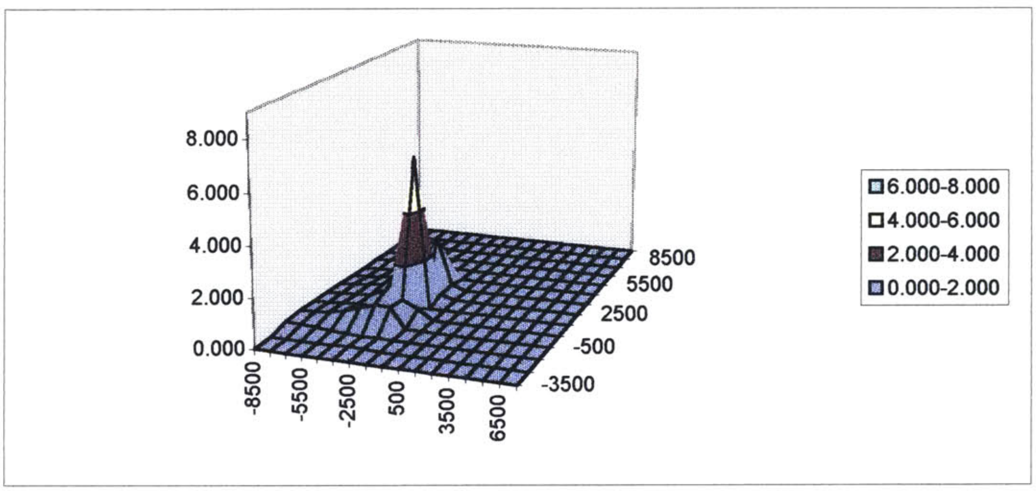


7 A.M.

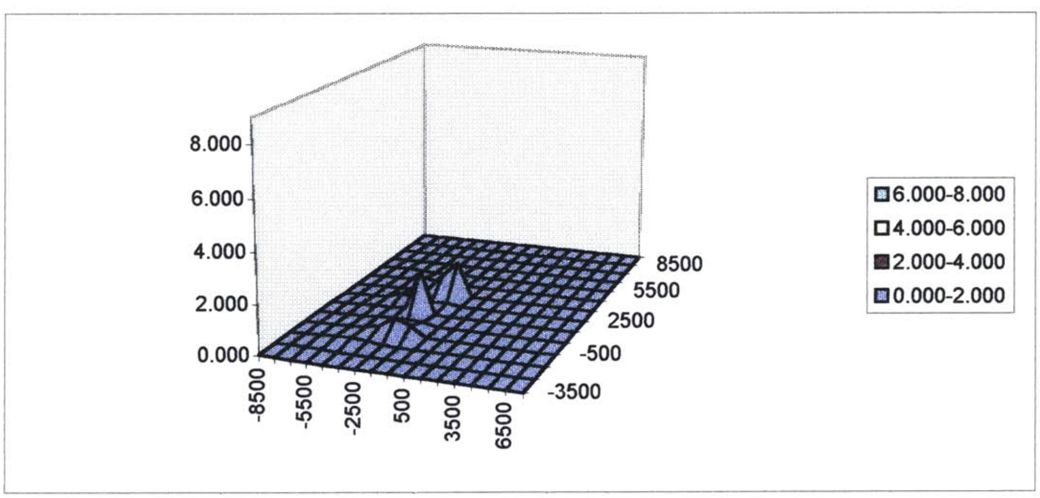
Model day CO concentrations



8 A.M.

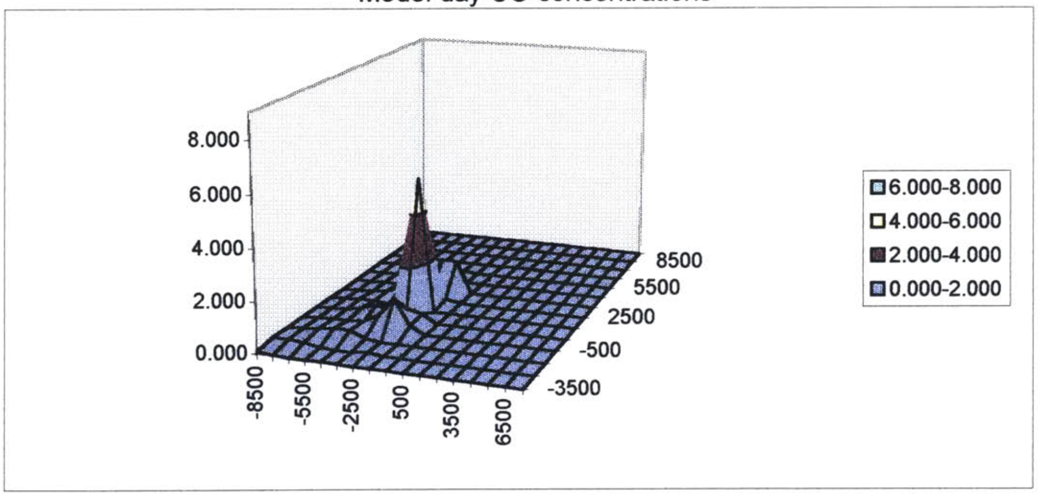


9 A.M.

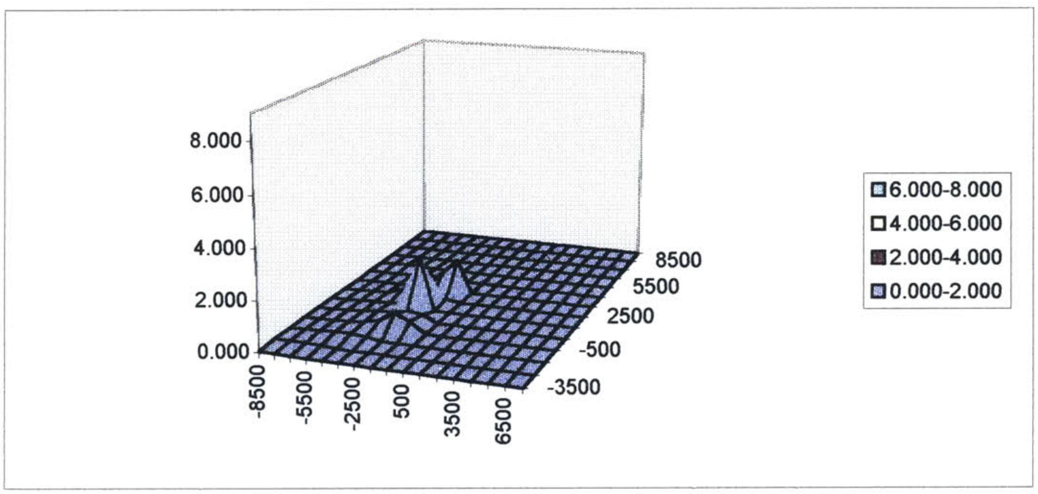


10 A.M.

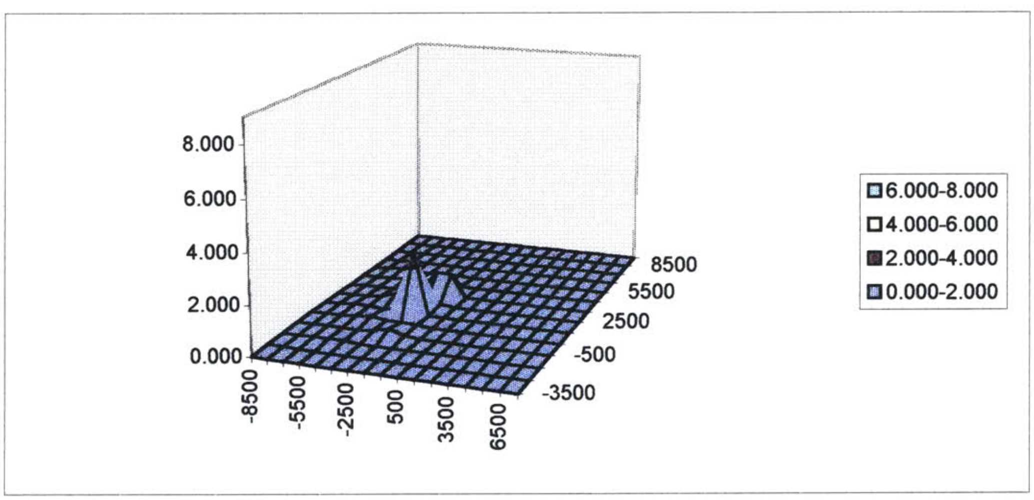
Model day CO concentrations



11 A.M.

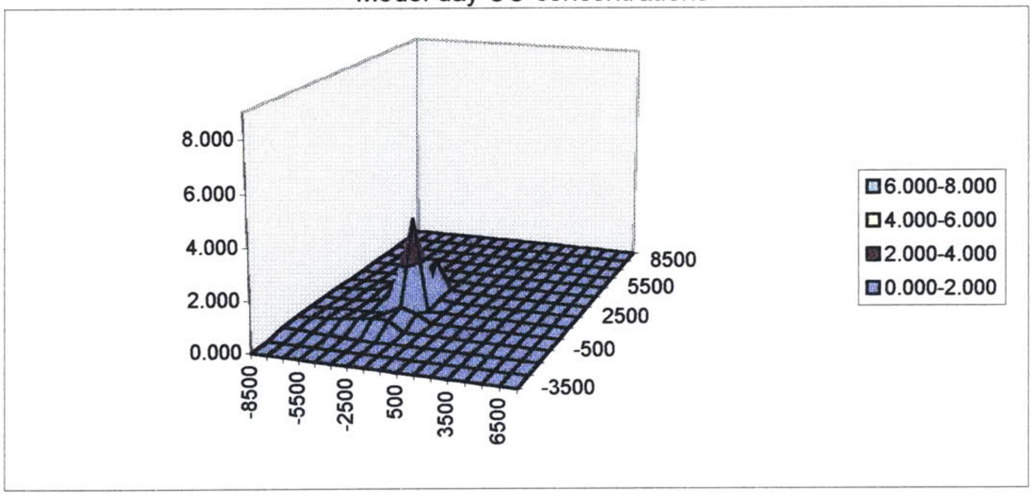


Noon

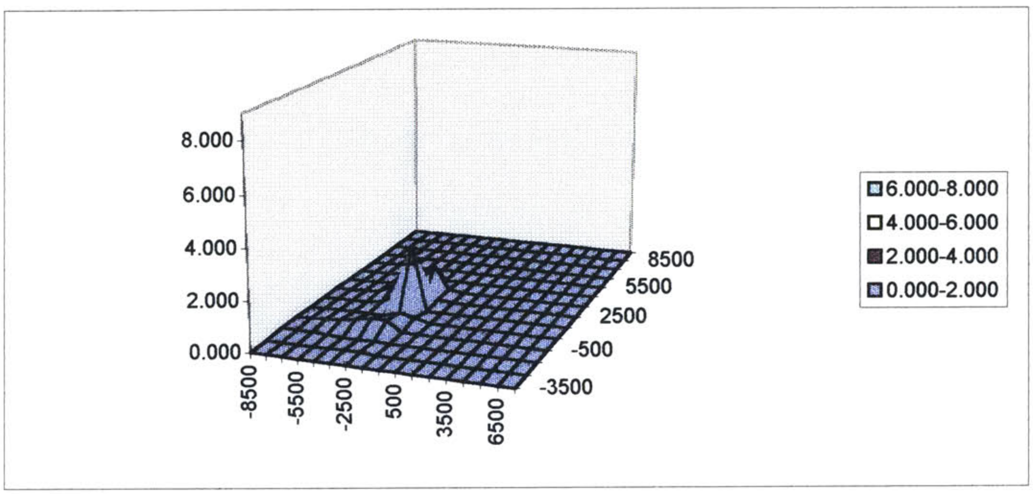


1 P.M.

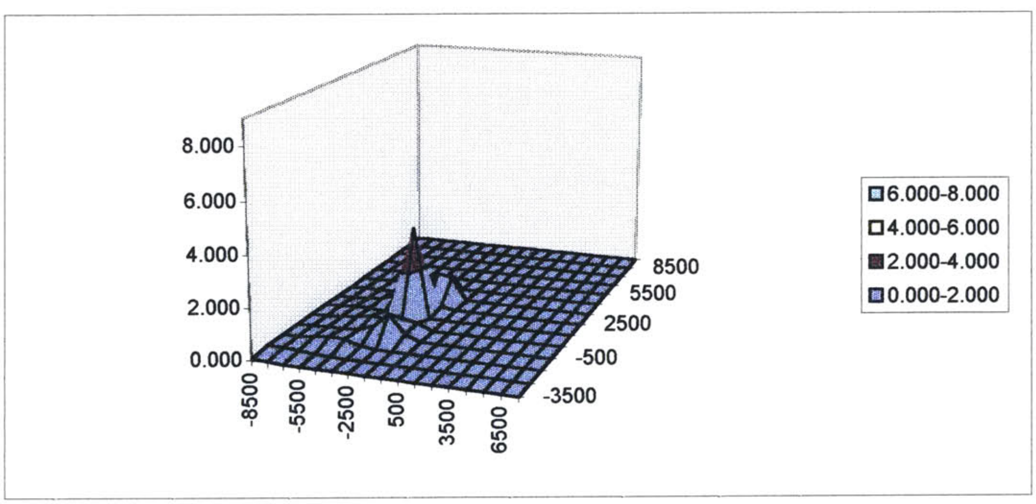
Model day CO concentrations



2 P.M.

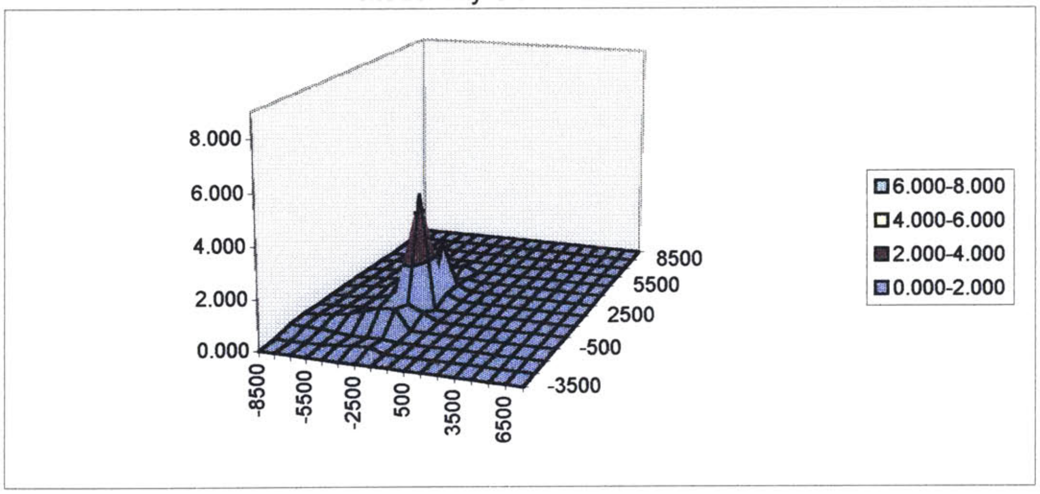


3 P.M.

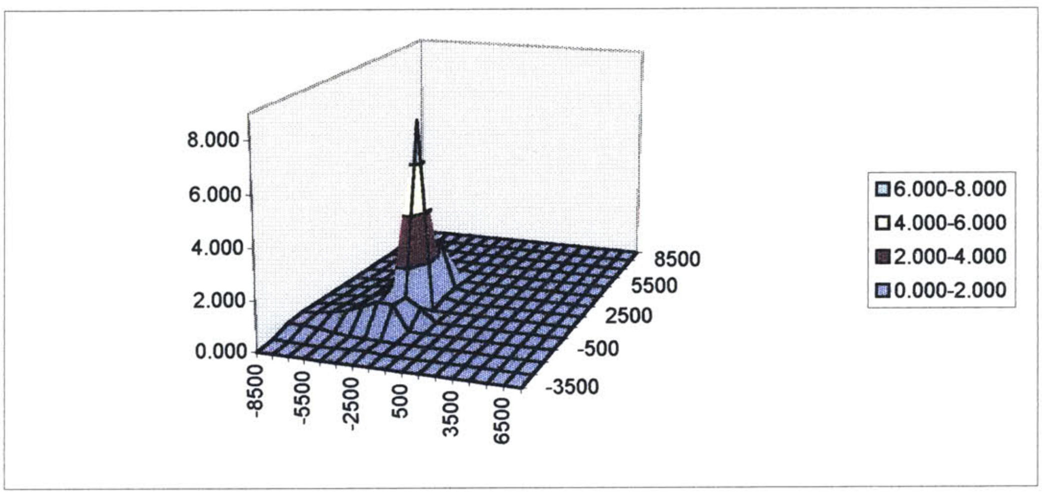


4 P.M.

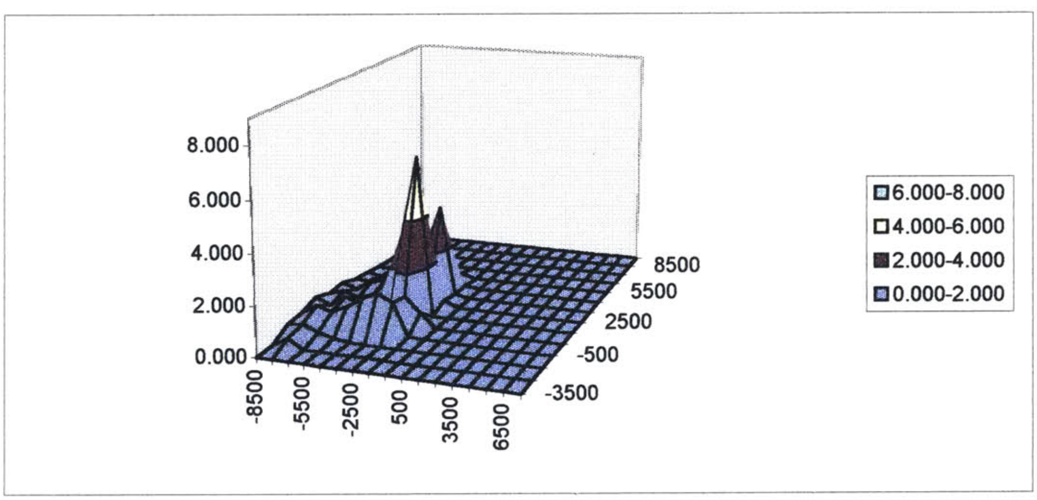
Model day CO concentrations



5 P.M.

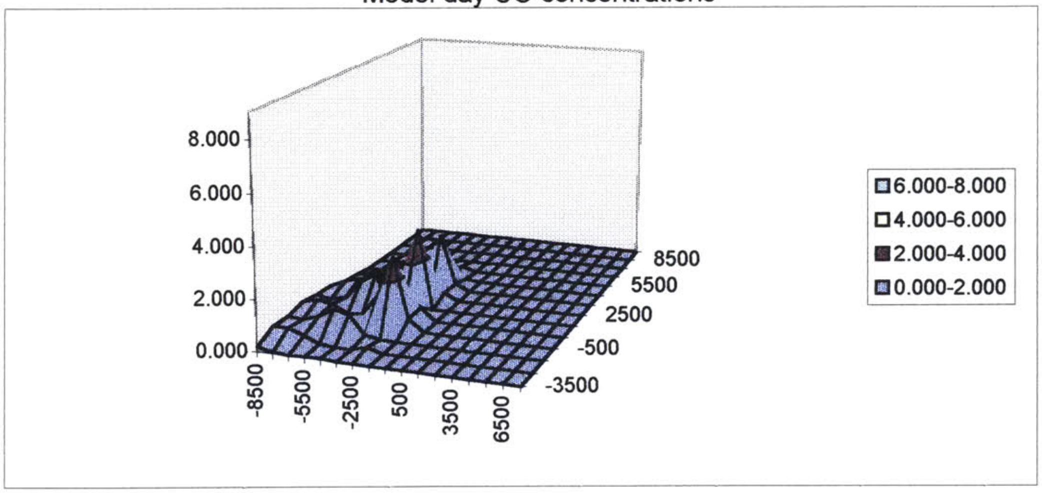


6 P.M.

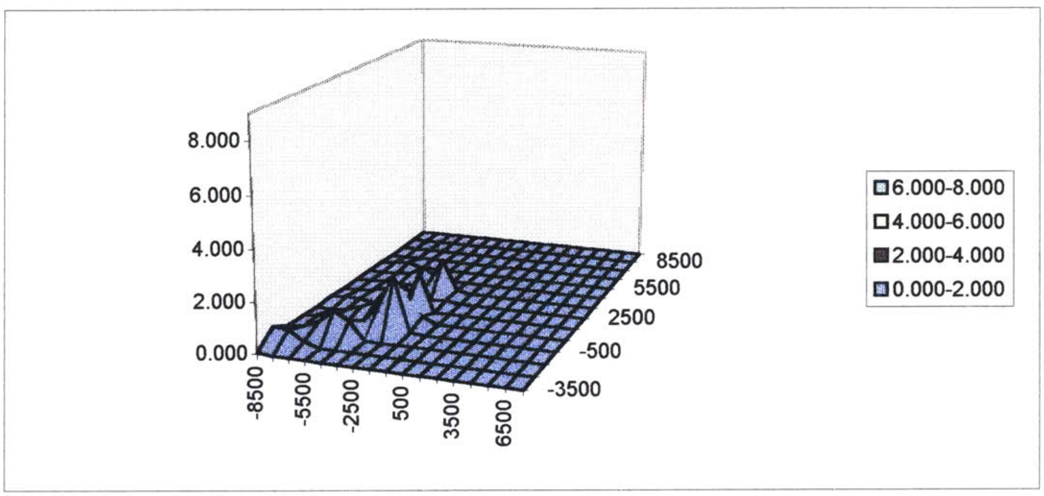


7 P.M.

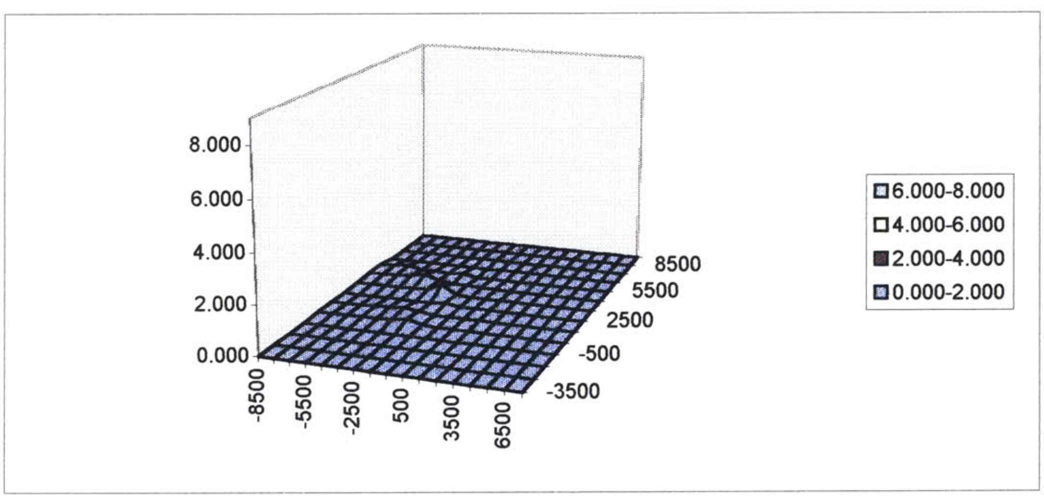
Model day CO concentrations



8 P.M.

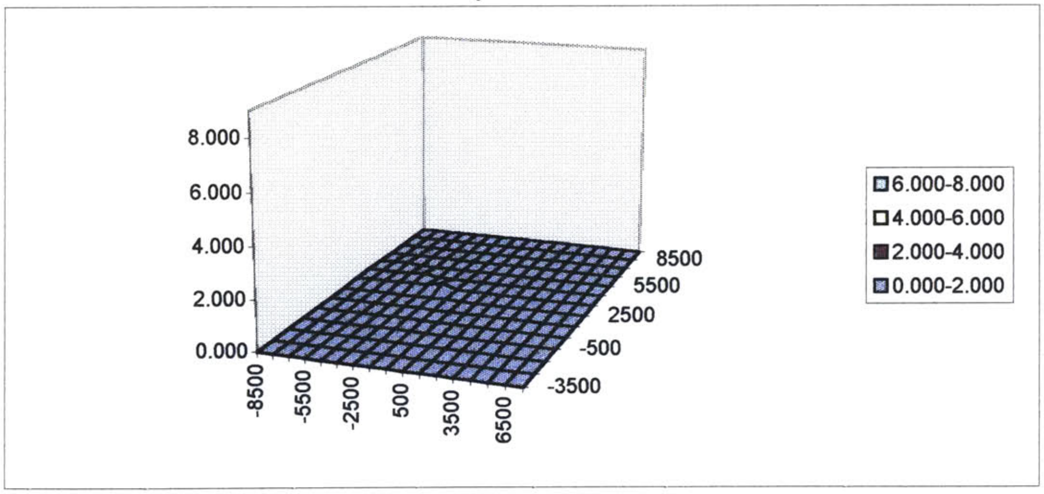


9 P.M.



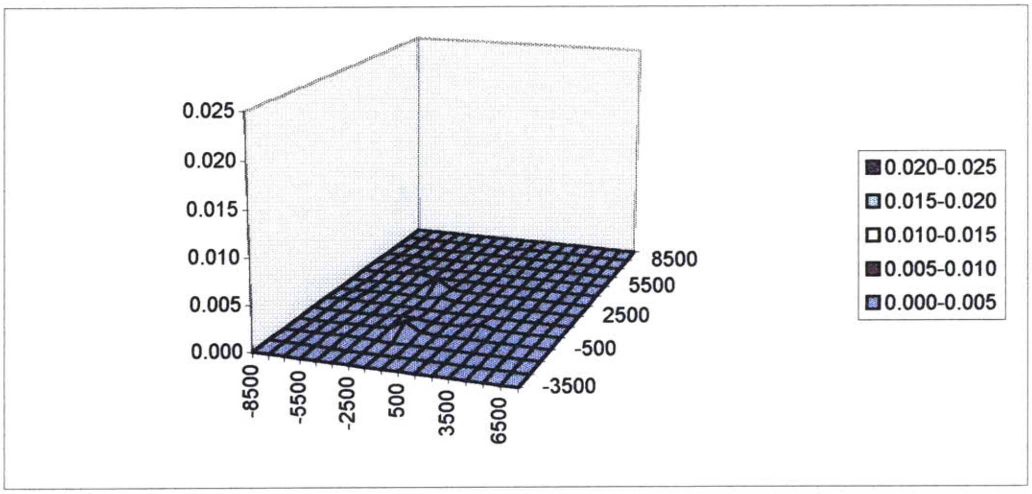
10 P.M.

Model day CO concentrations

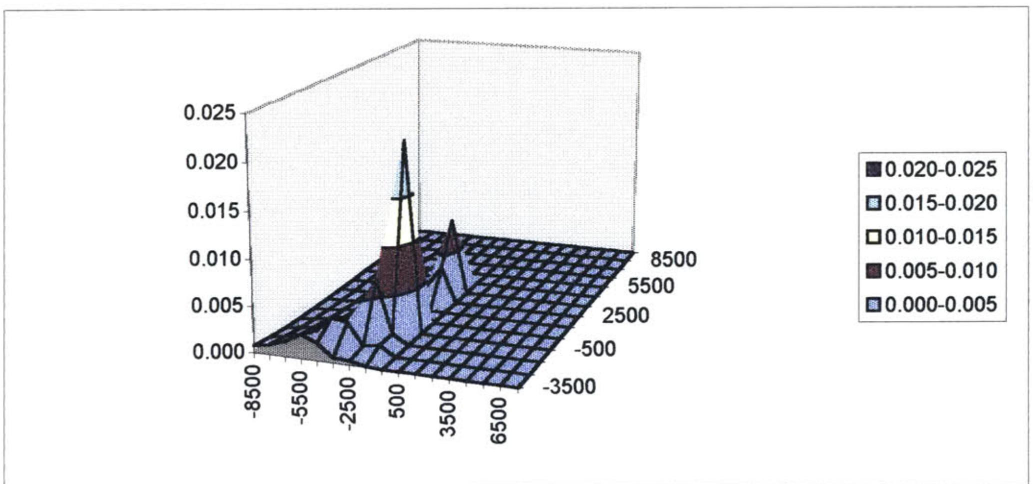


11 P.M.

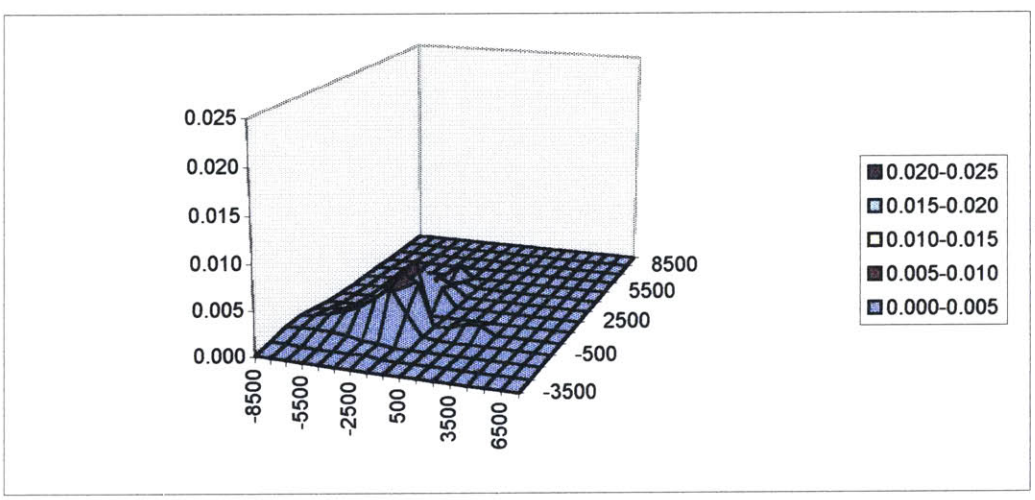
Model day SO_X concentrations



5 A.M.

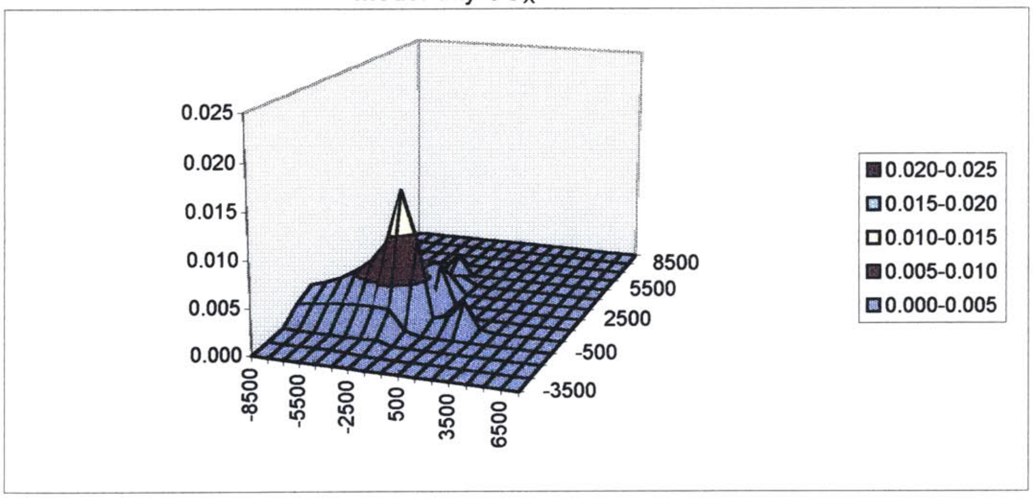


6 A.M.

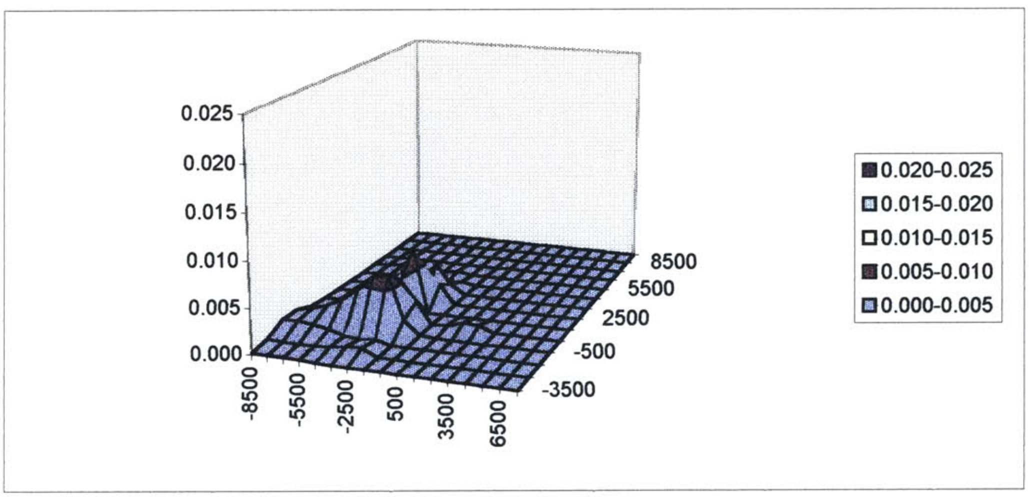


7 A.M.

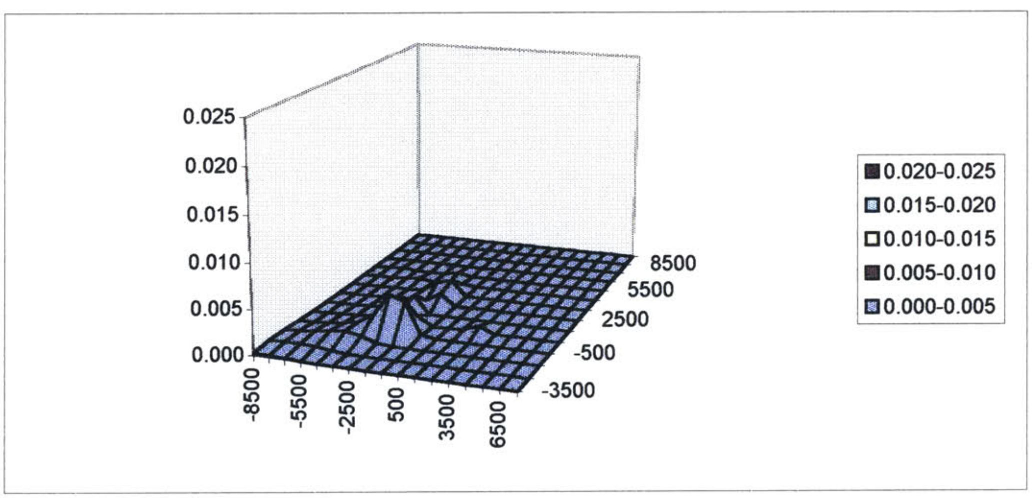
Model day SO_X concentrations



8 A.M.

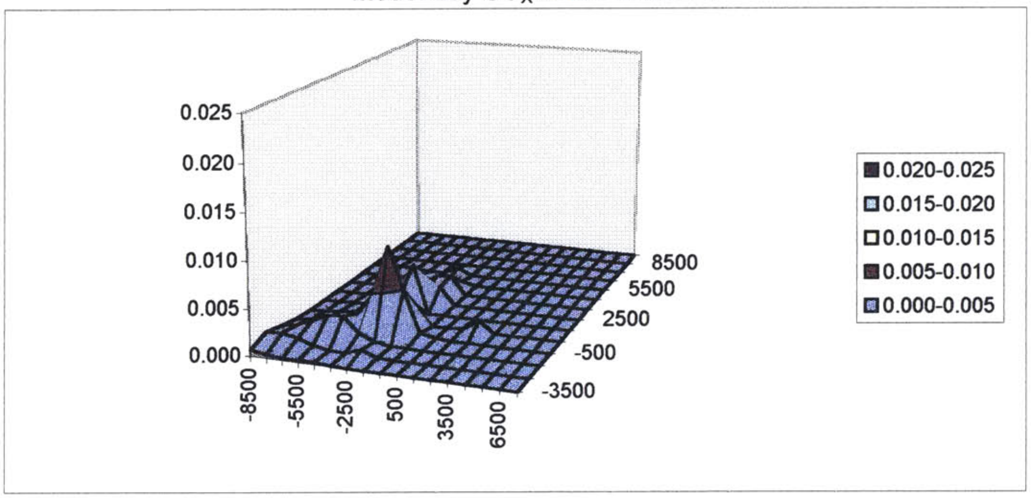


9 A.M.

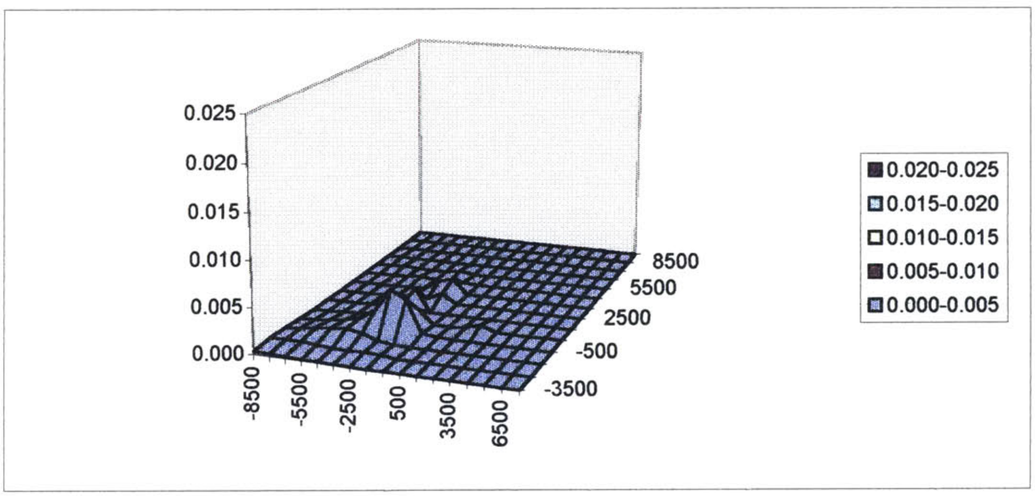


10 A.M.

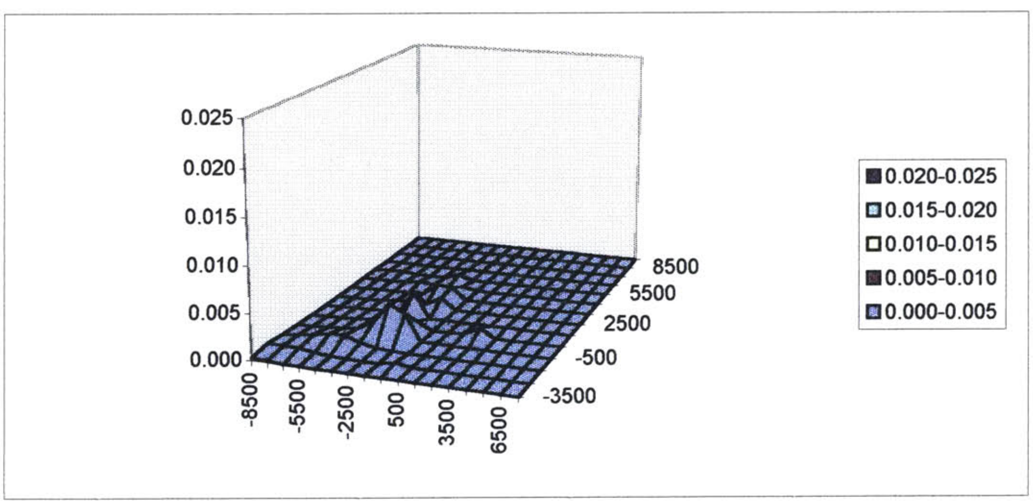
Model day SO_X concentrations



11 A.M.

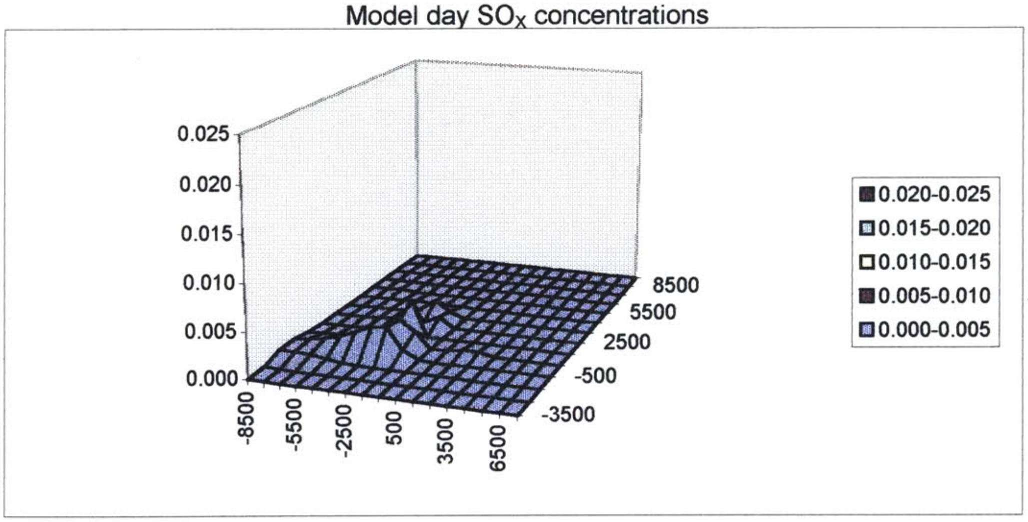


Noon

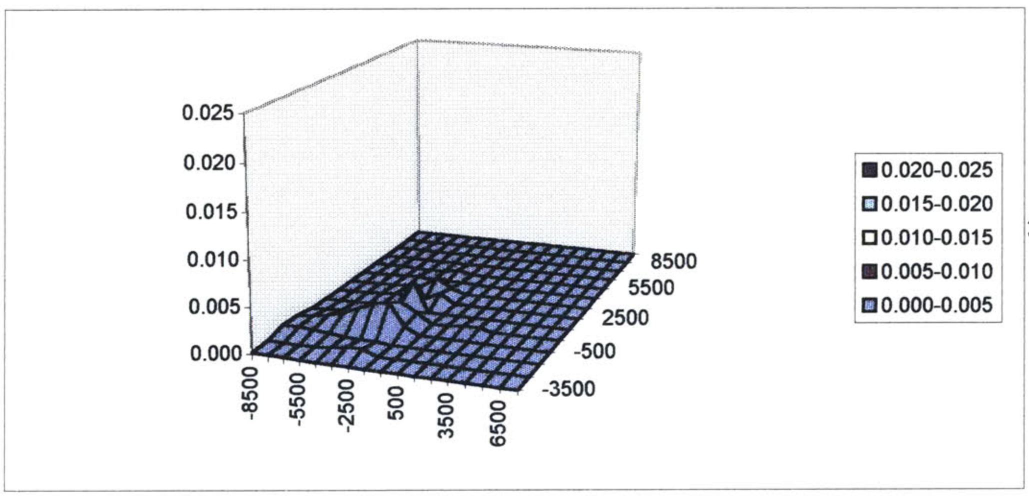


1 P.M.

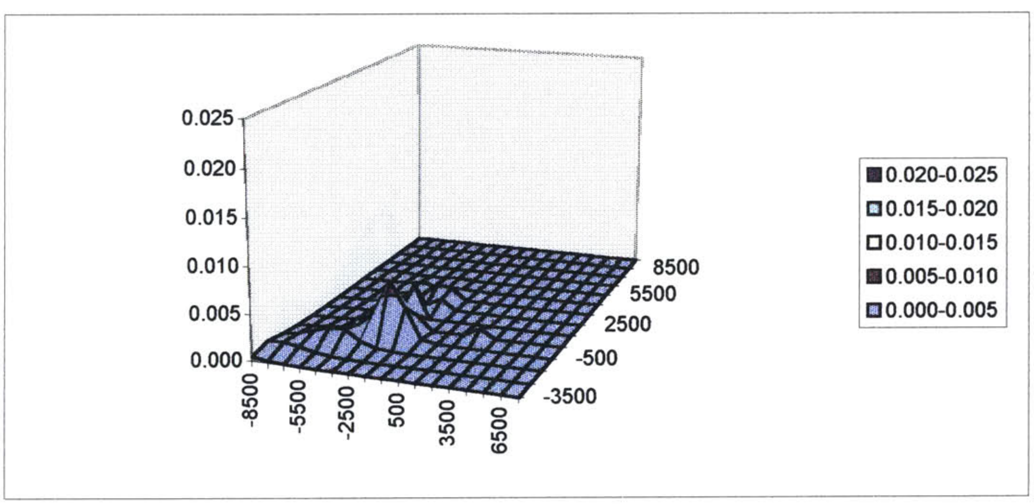
Model day SO_X concentrations



2 P.M.

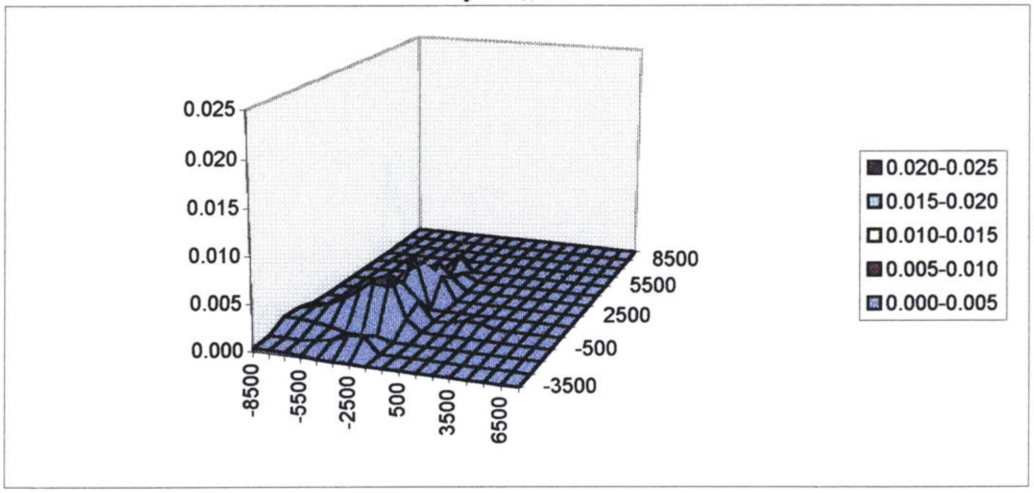


3 P.M.

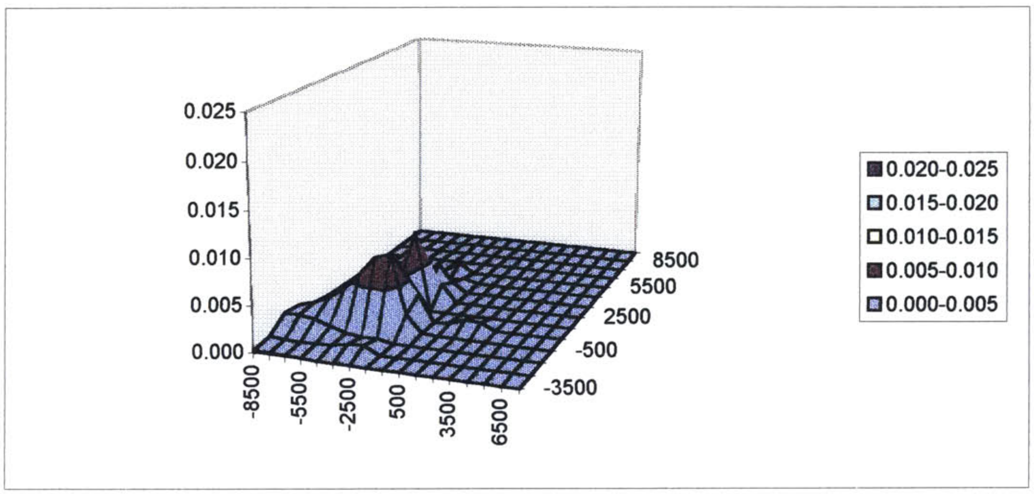


4 P.M.

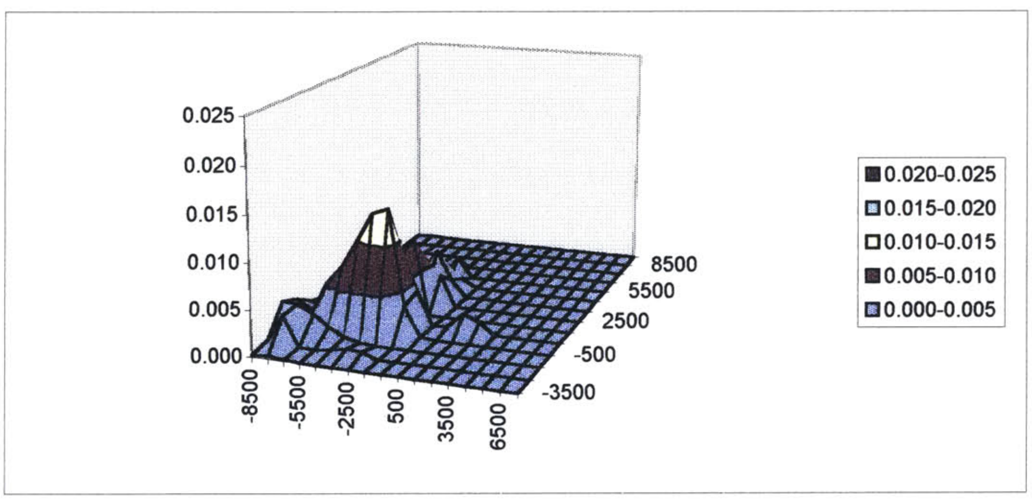
Model day SO_X concentrations



5 P.M.

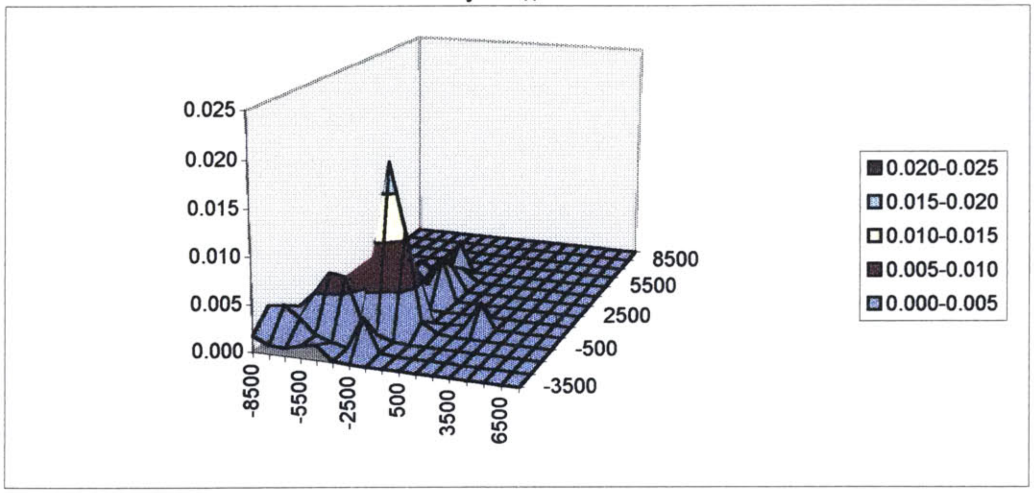


6 P.M.

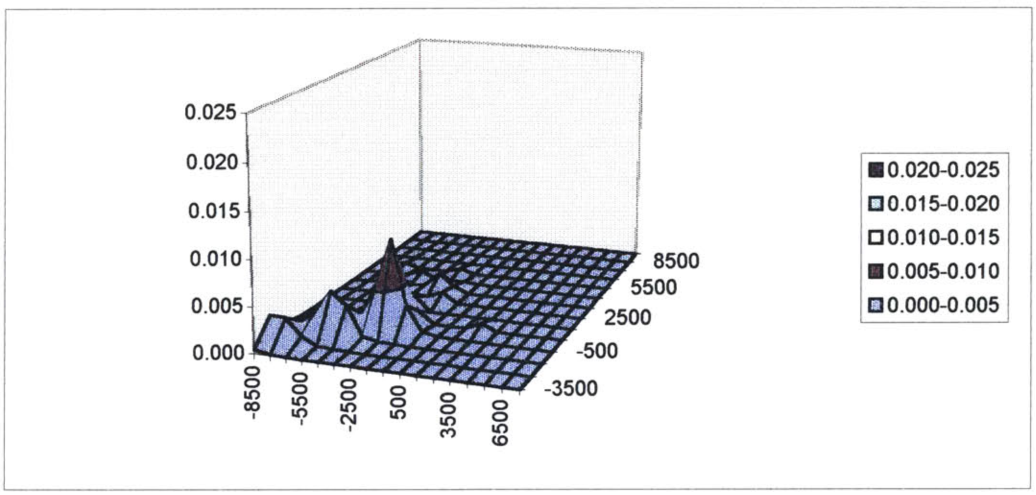


7 P.M.

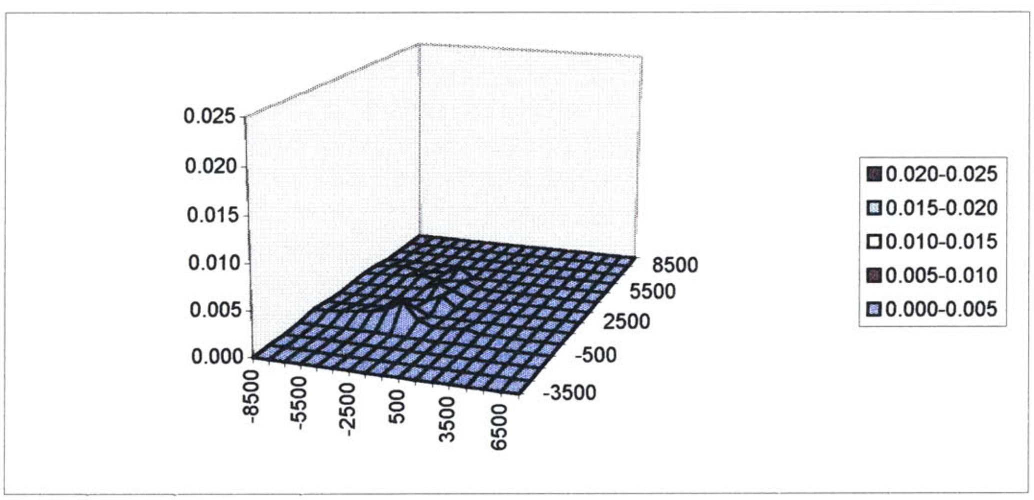
Model day SO_X concentrations



8 P.M.

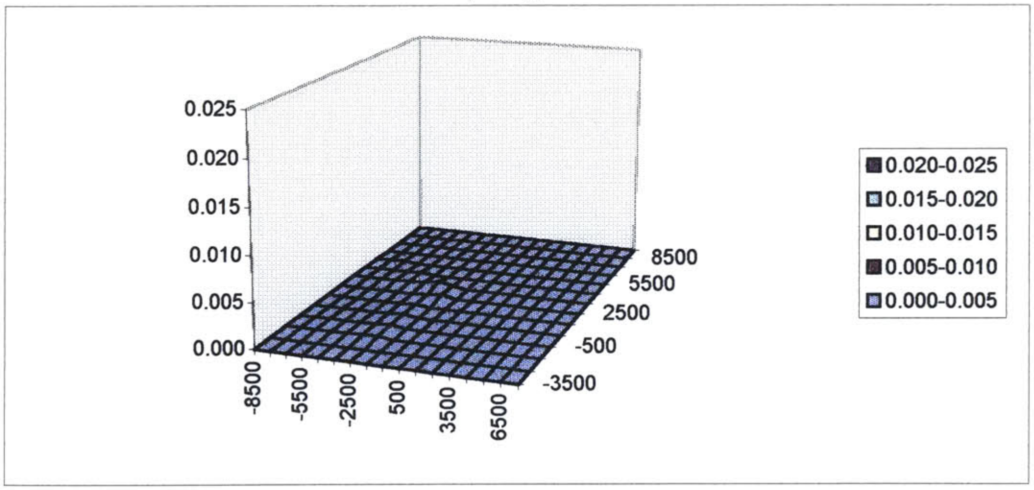


9 P.M.



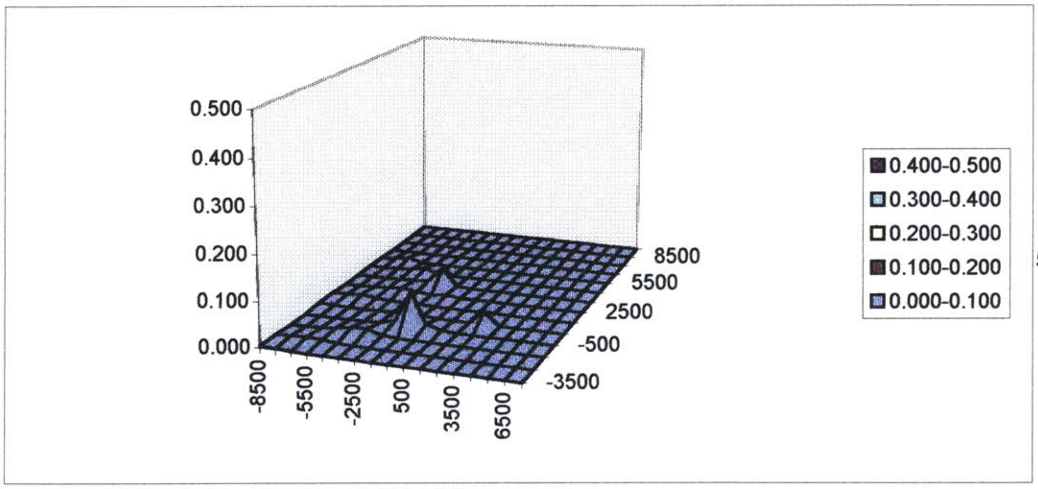
10 P.M.

Model day SO_X concentrations

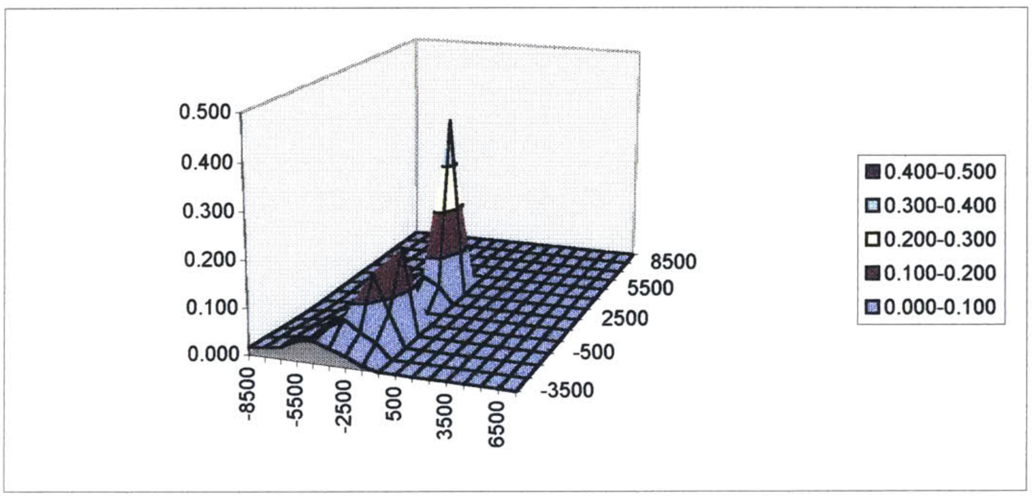


11 P.M.

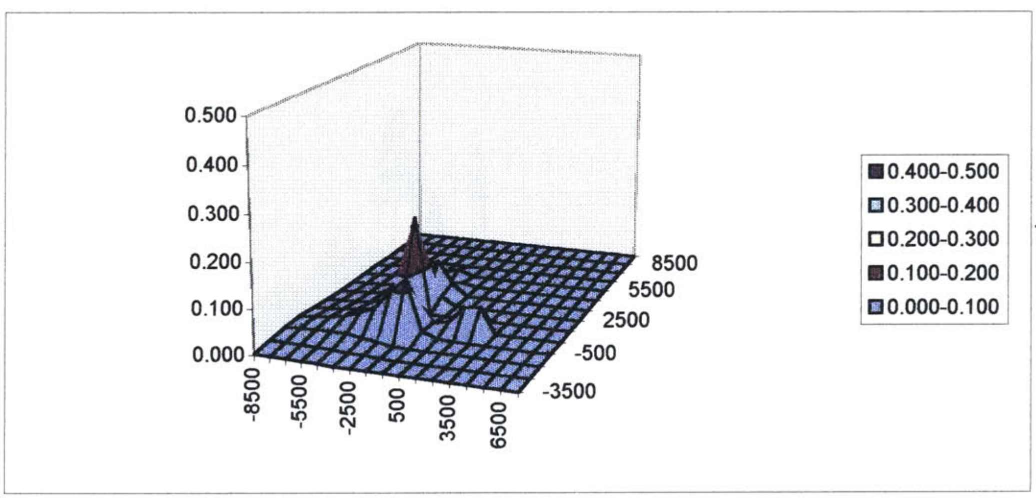
Low-wind condition NO_X concentrations



5 A.M.

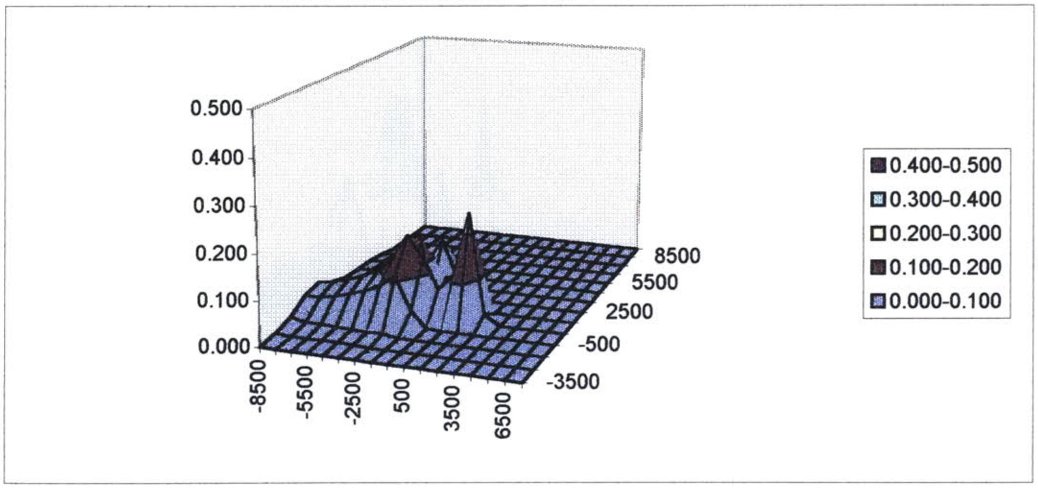


6 A.M.

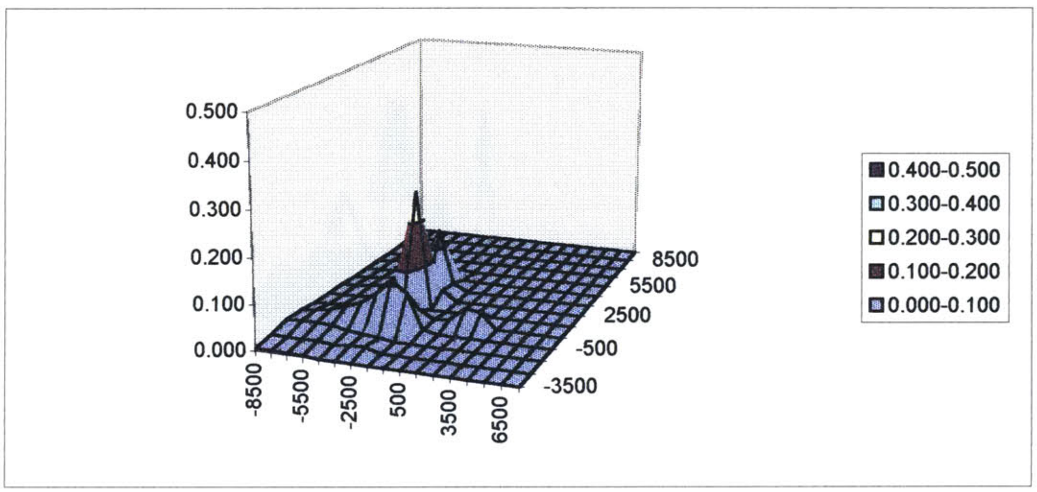


7 A.M.

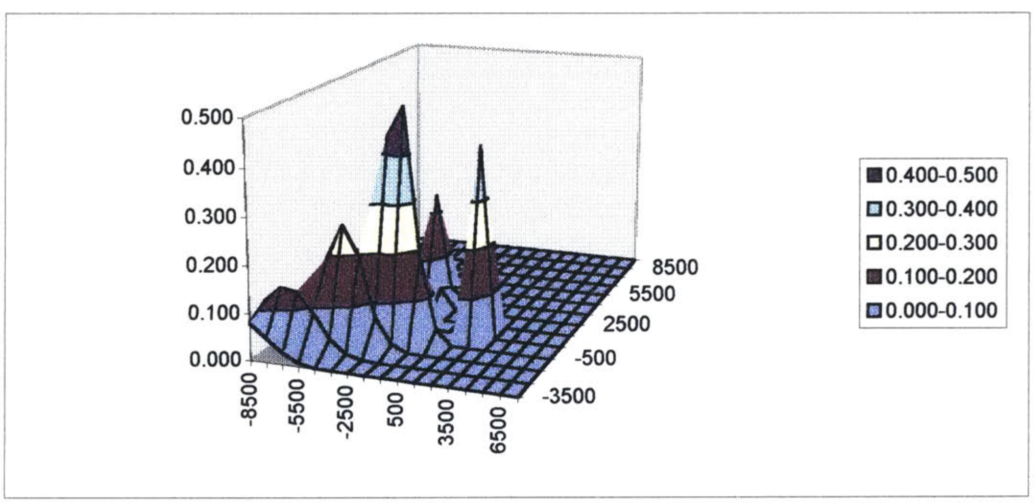
Low-wind condition NO_X concentrations



8 A.M.



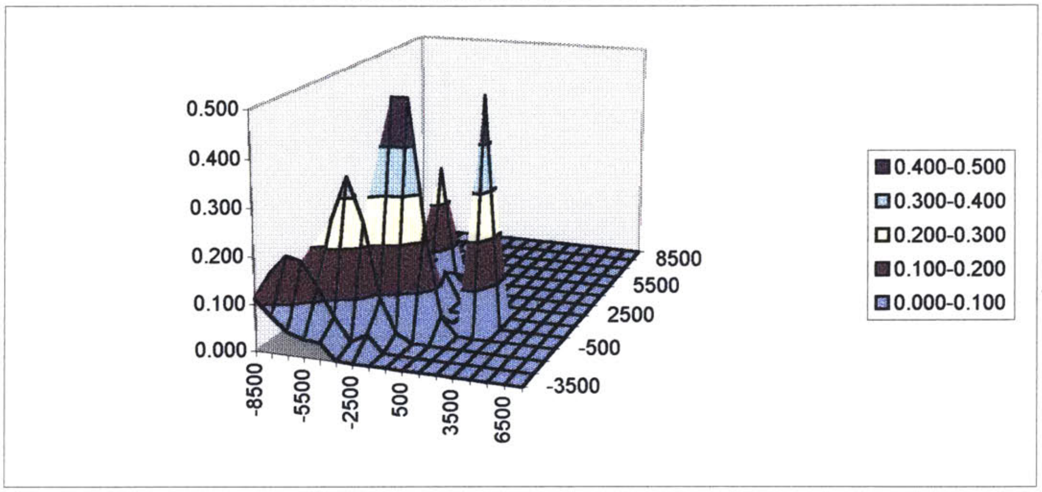
9 A.M.



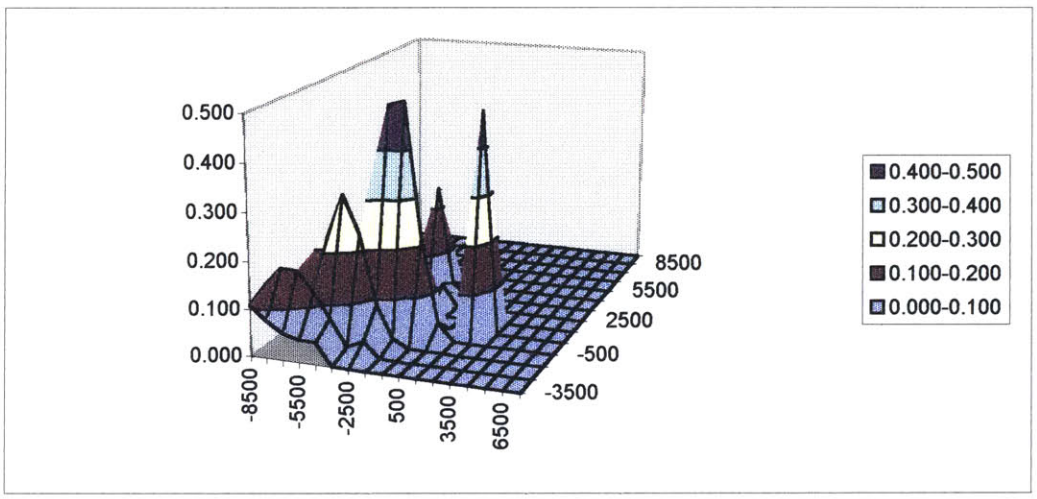
10 A.M.*

*Peak concentrations are greater than 0.500 PPM

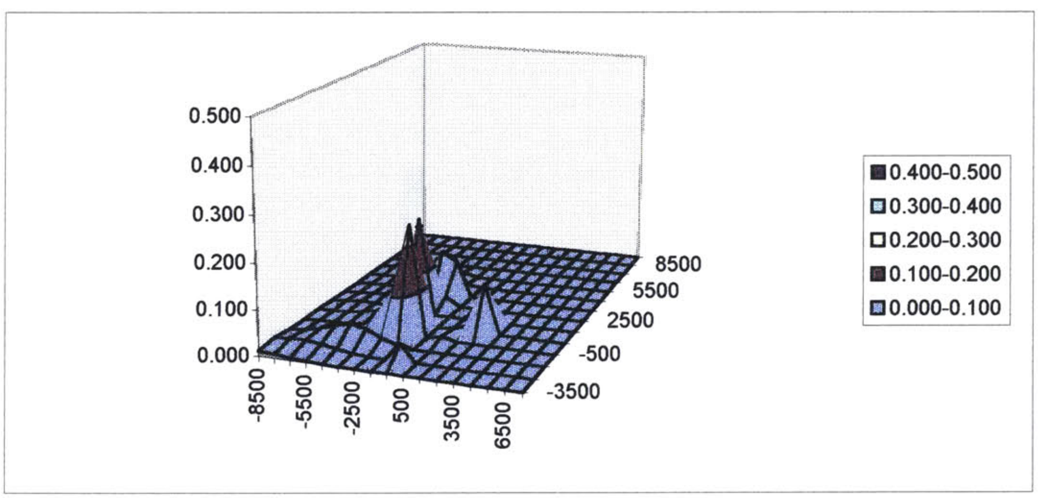
Low-wind condition NO_X concentrations



11 A.M.*



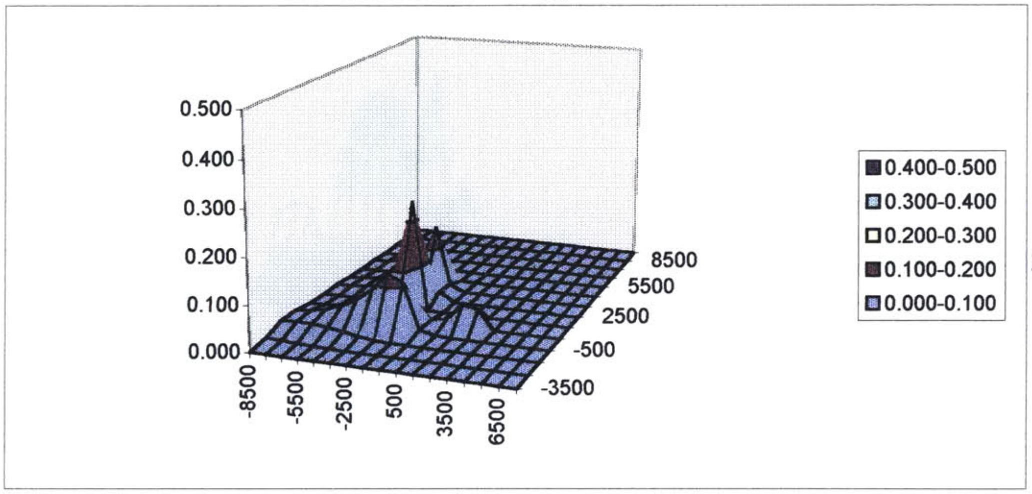
Noon*



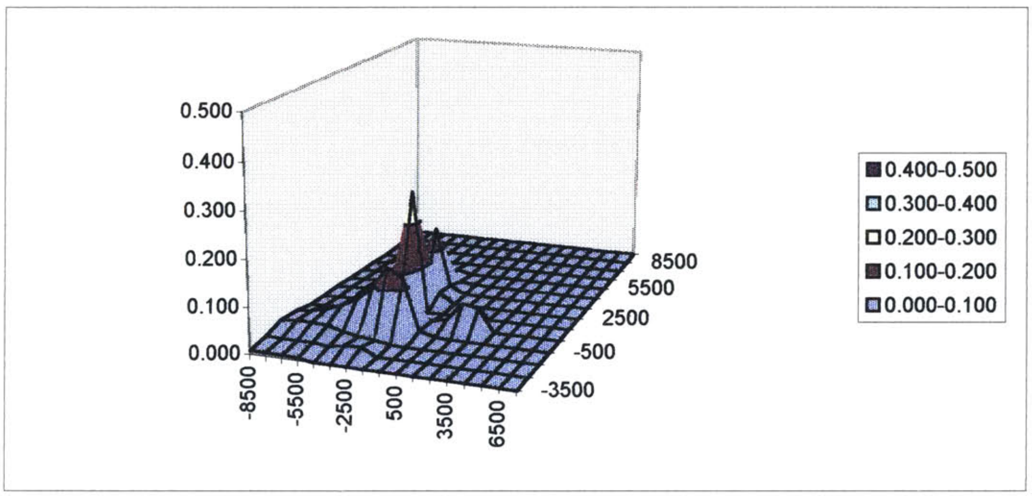
1 P.M.

*Peak concentrations are greater than 0.500 PPM

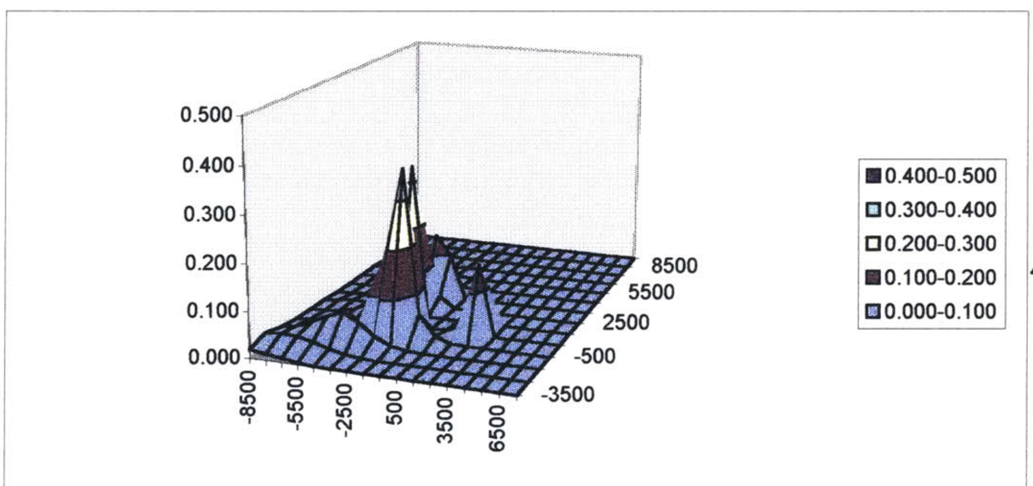
Low-wind condition NO_X concentrations



2 P.M.

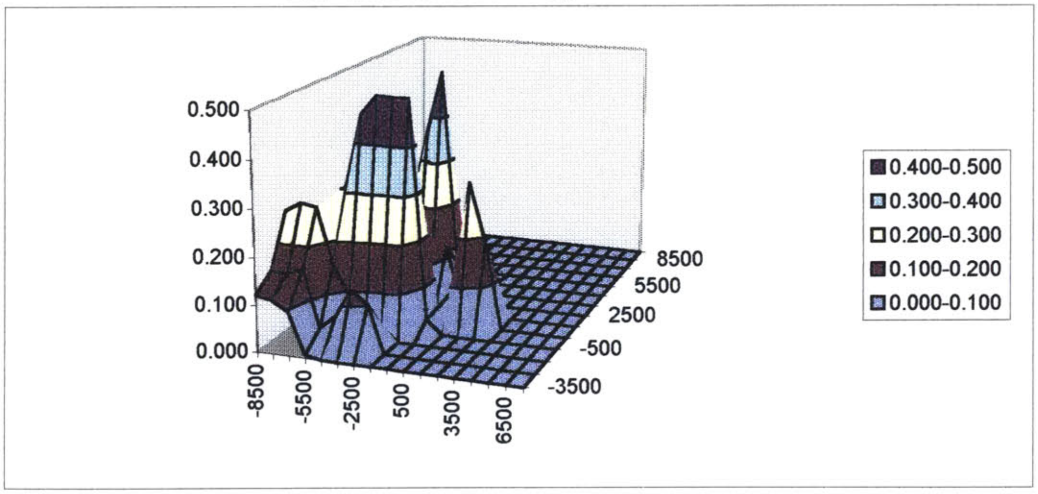


3 P.M.

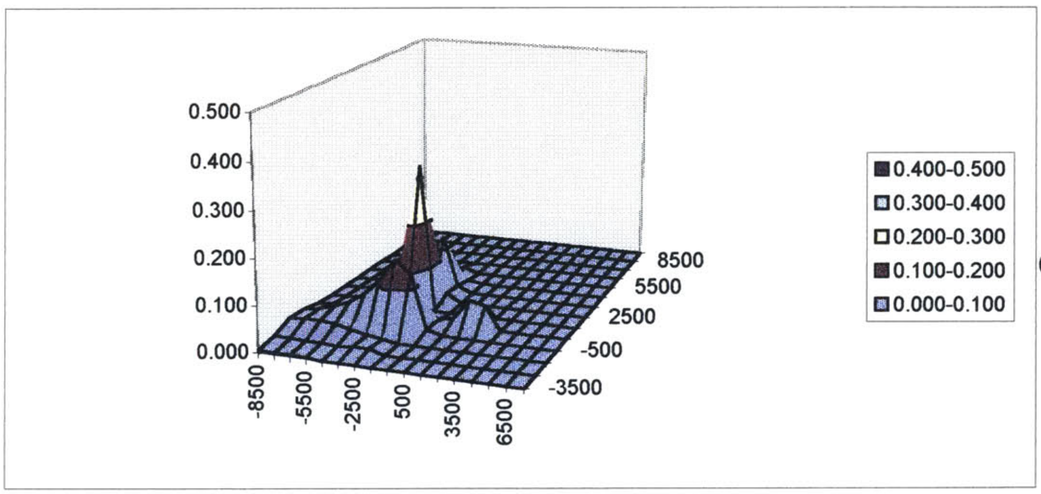


4 P.M.

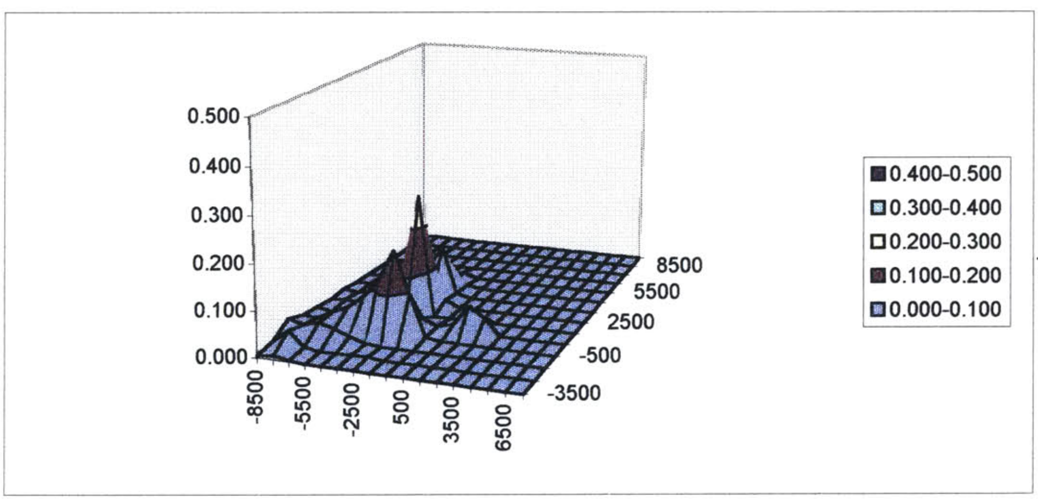
Low-wind condition NO_X concentrations



5 P.M.*



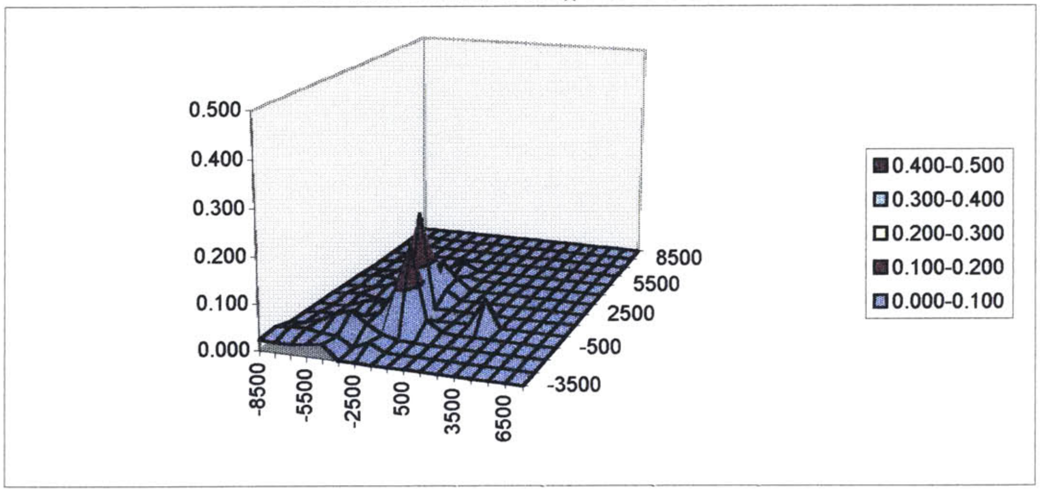
6 P.M.



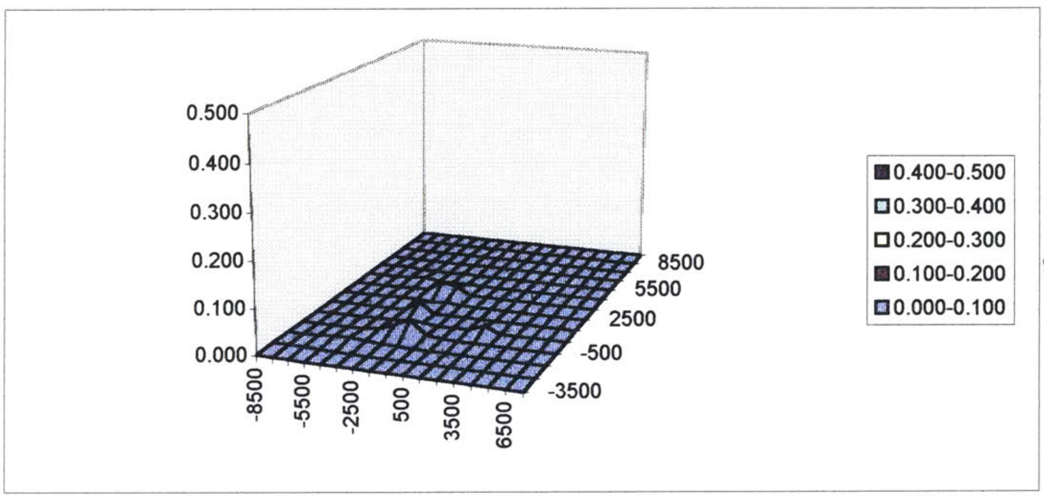
7 P.M.

*Peak concentrations are greater than 0.500 PPM

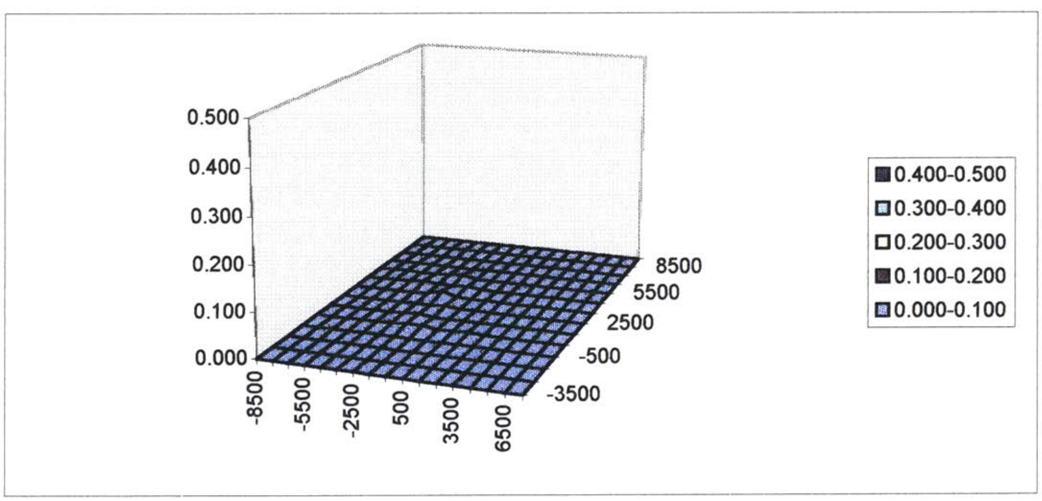
Low-wind condition NO_X concentrations



8 P.M.

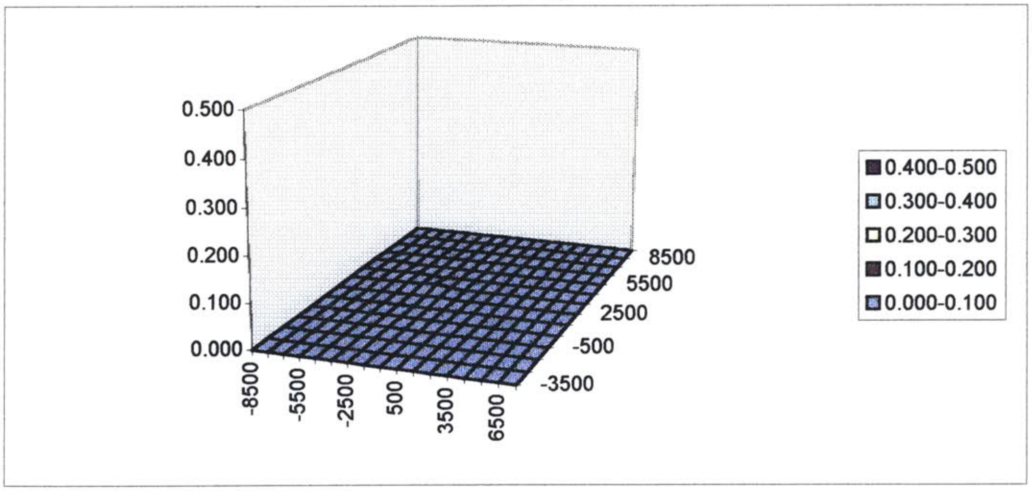


9 P.M.



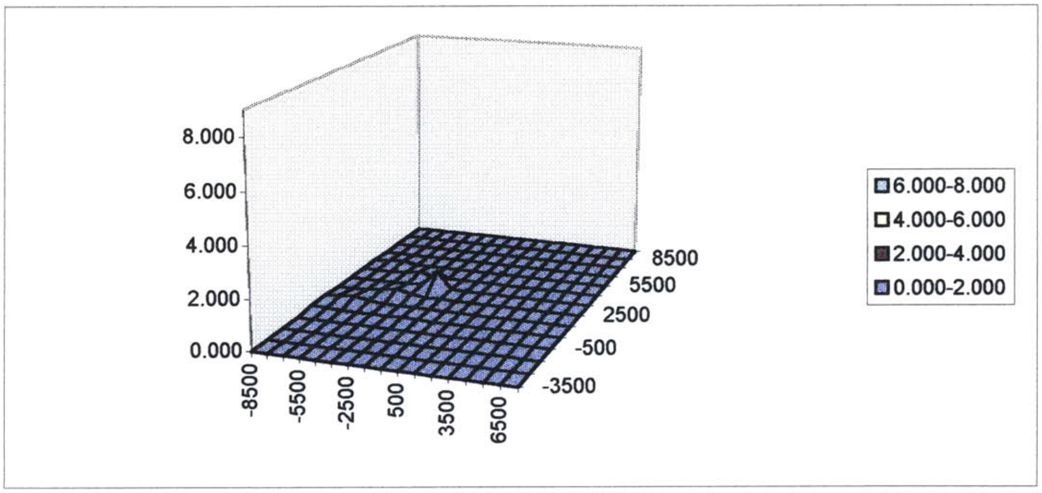
10 P.M.

Low-wind condition NO_X concentrations

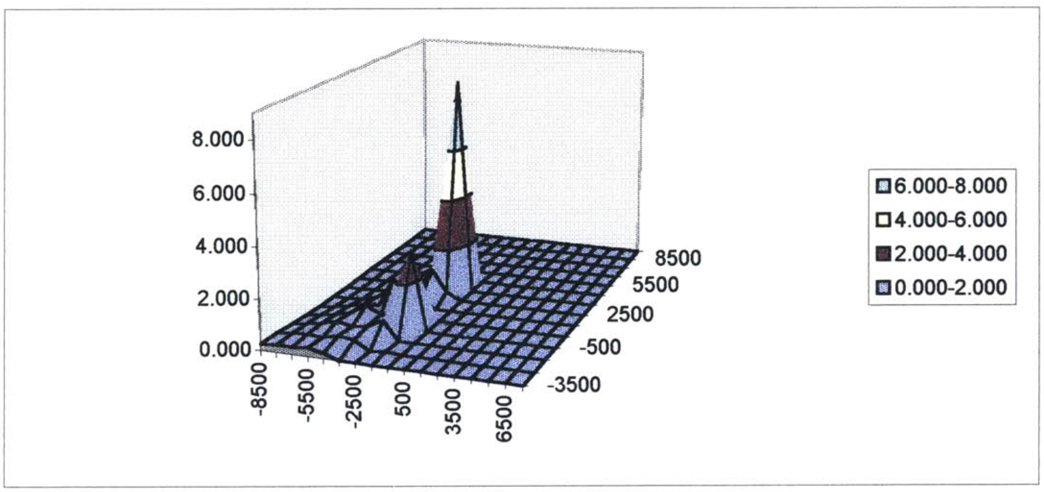


11 P.M.

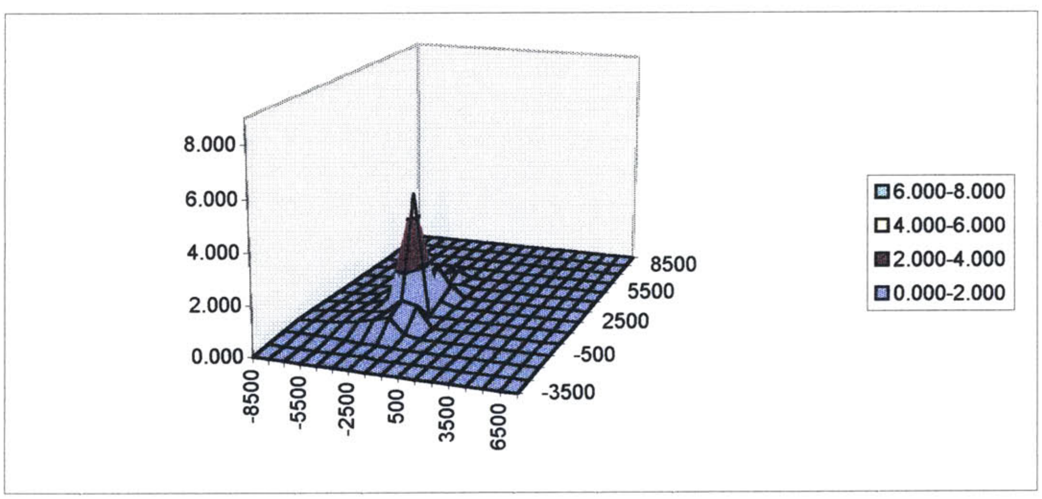
Low-wind condition CO concentrations



5 A.M.



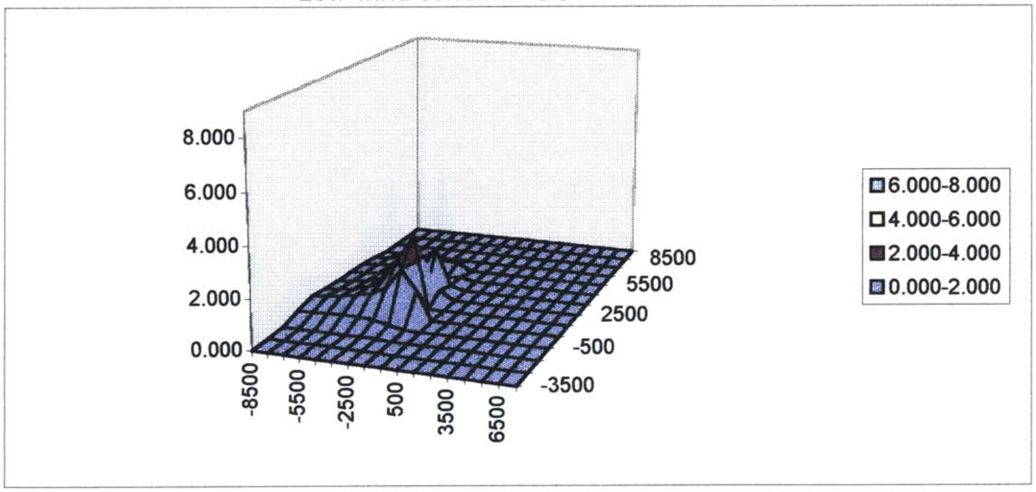
6 A.M.*



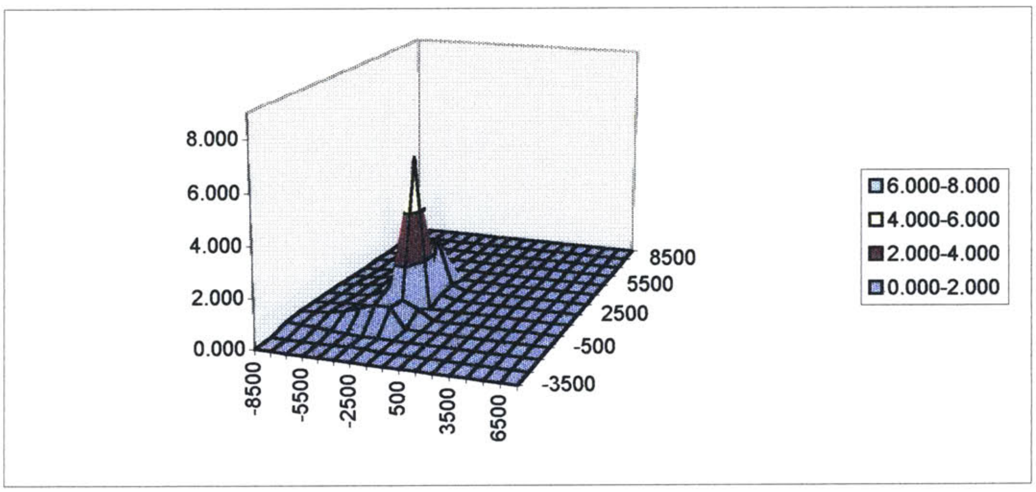
7 A.M.

*Peak concentrations are greater than 8.000 PPM

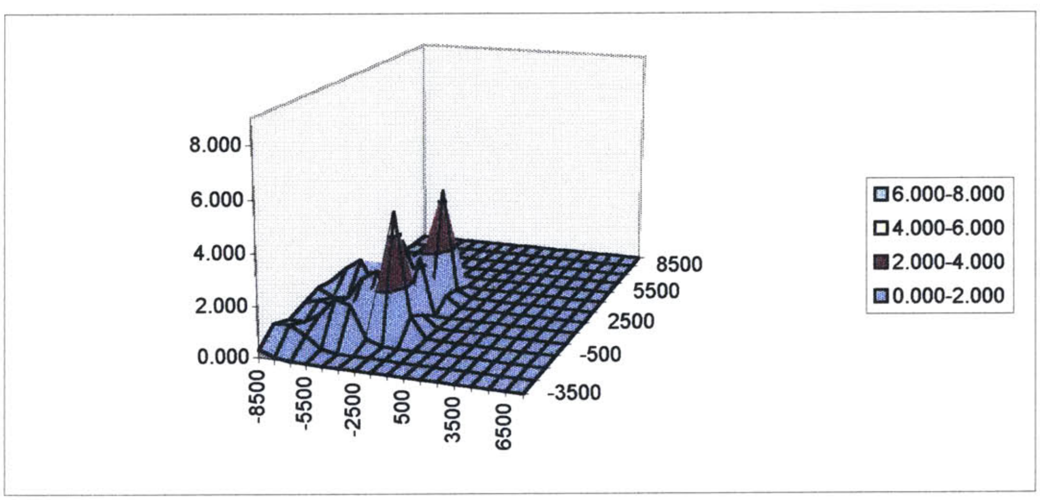
Low-wind condition CO concentrations



8 A.M.

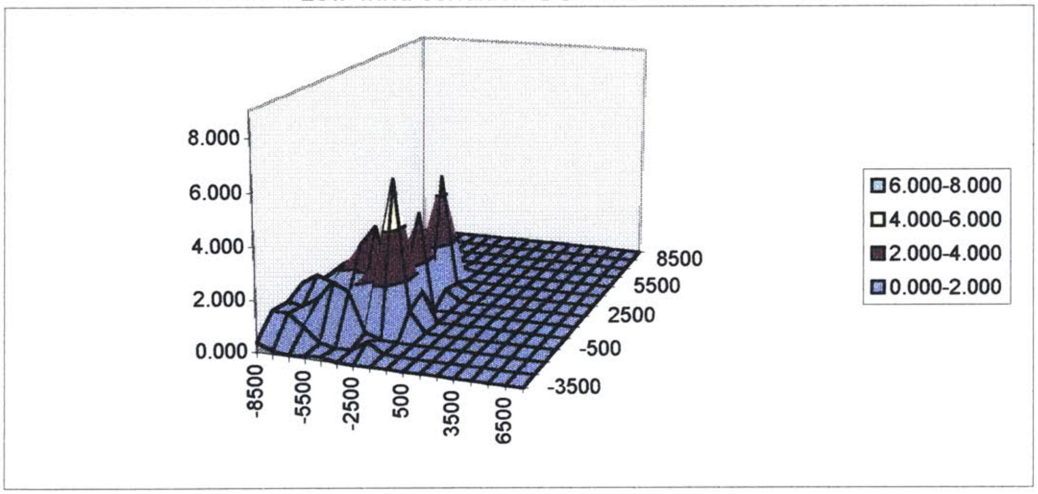


9 A.M.

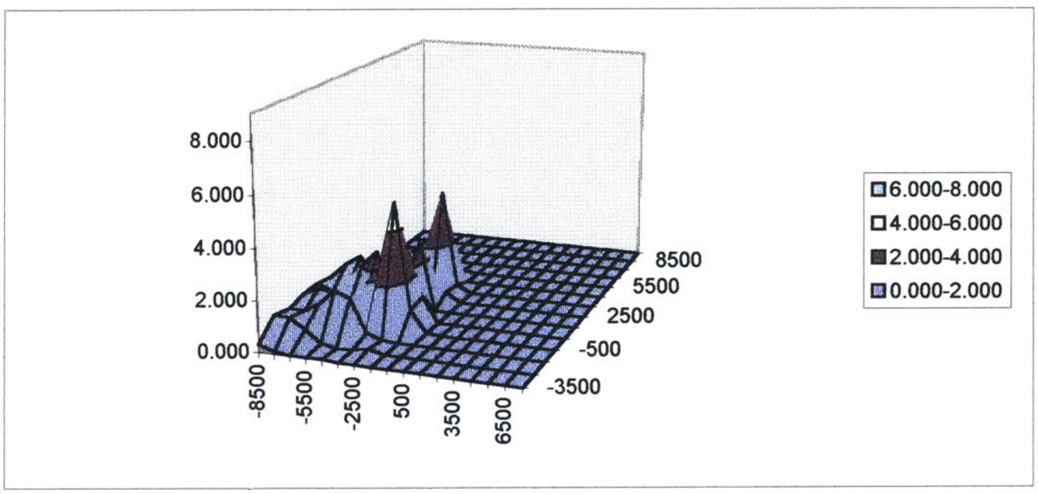


10 A.M.

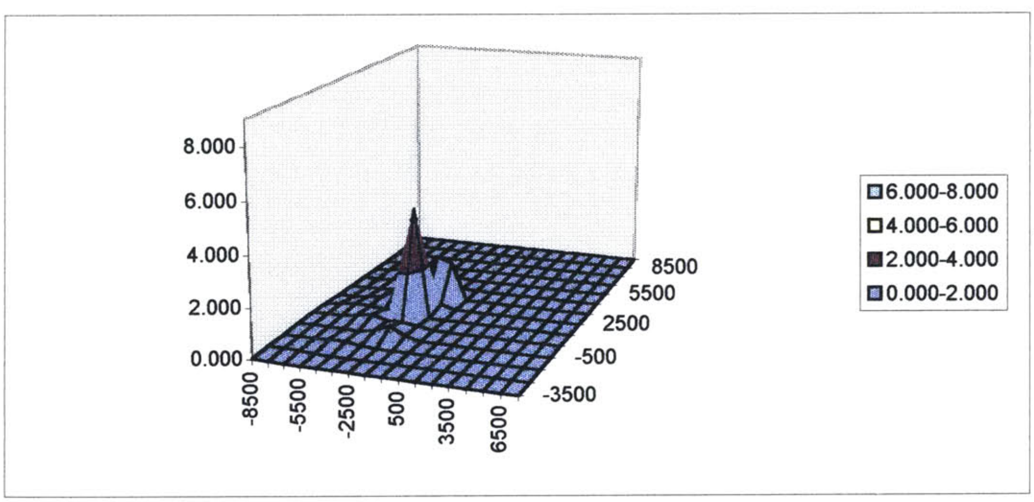
Low-wind condition CO concentrations



11 A.M.

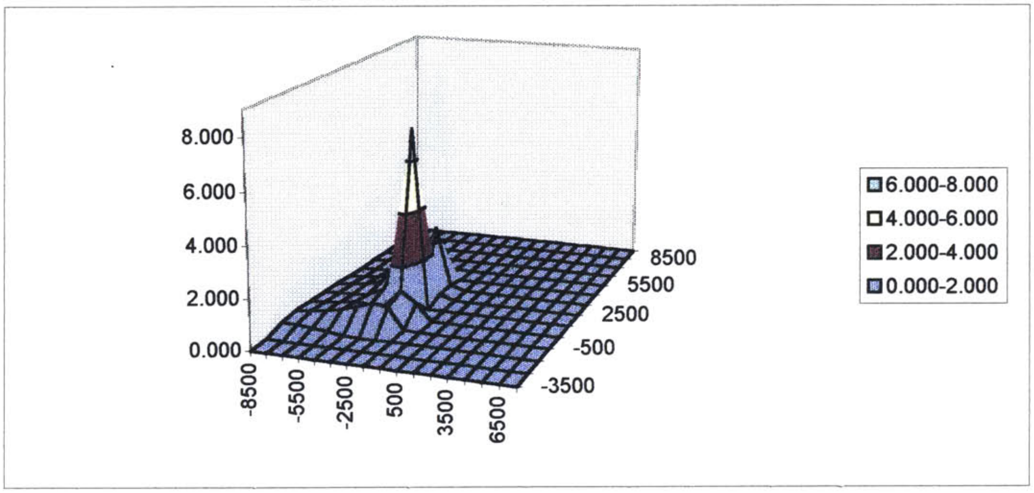


Noon

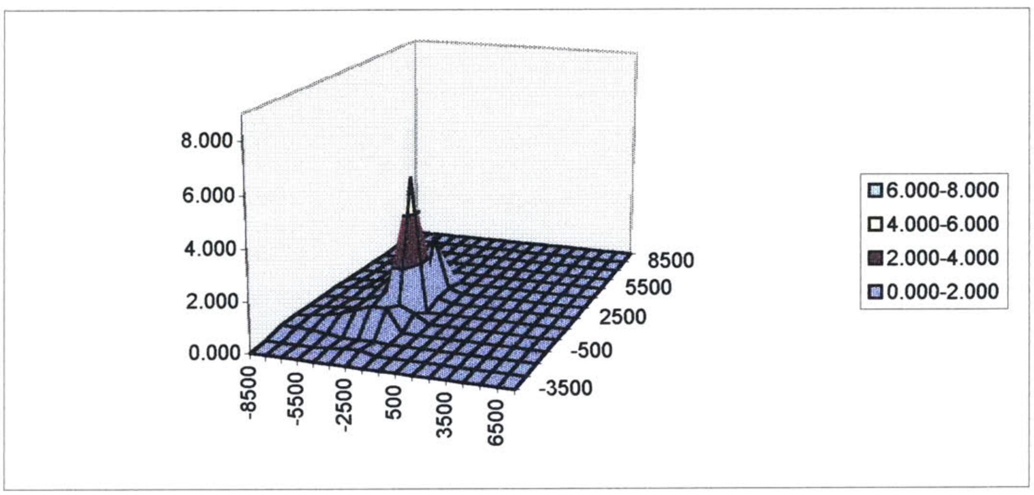


1 P.M.

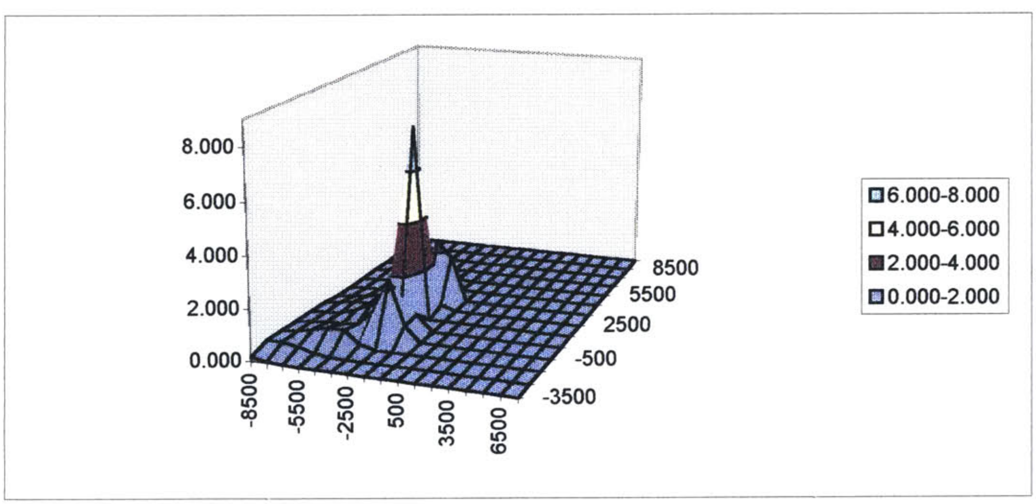
Low-wind condition CO concentrations



2 P.M.

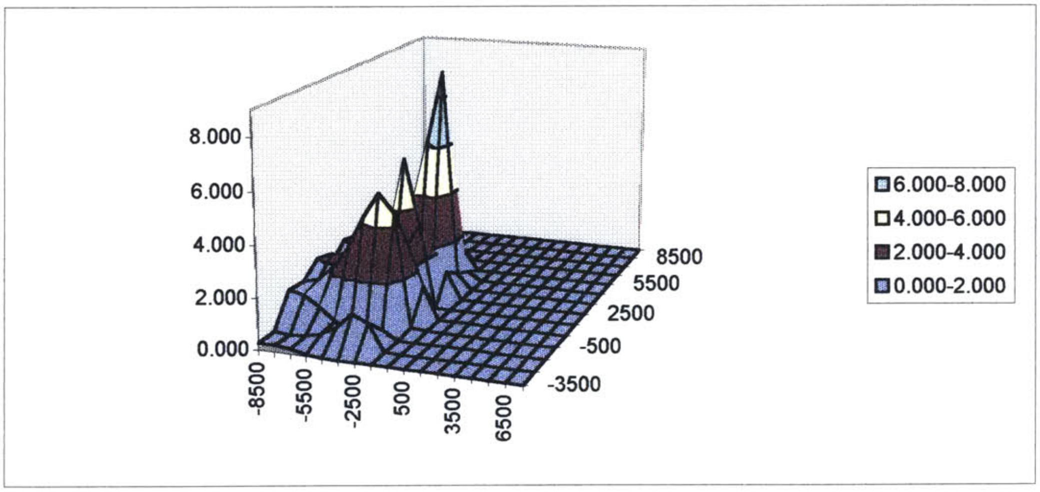


3 P.M.

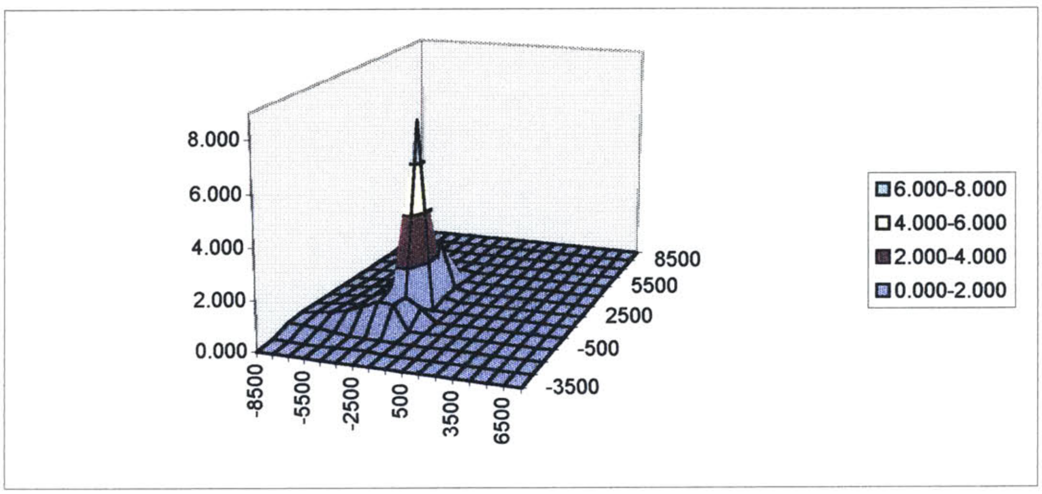


4 P.M.

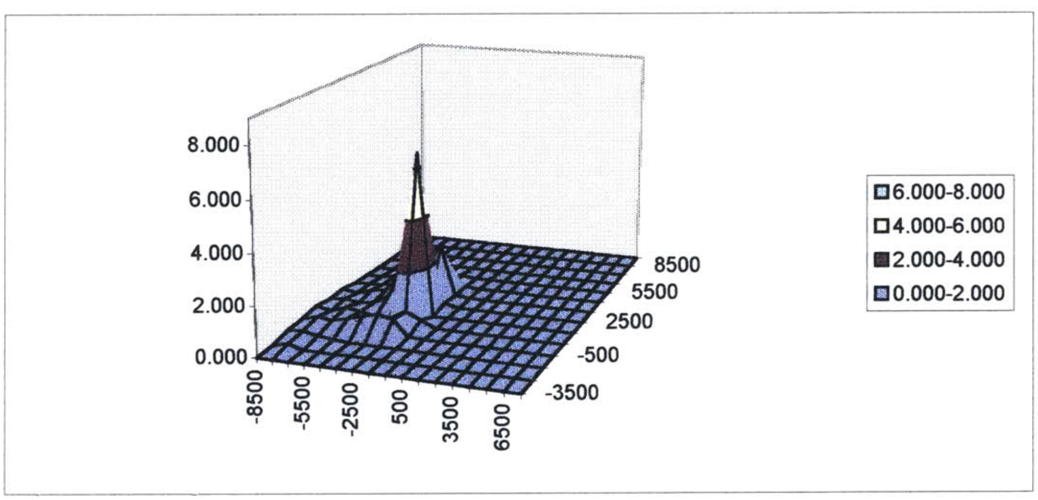
Low-wind condition CO concentrations



5 P.M.*



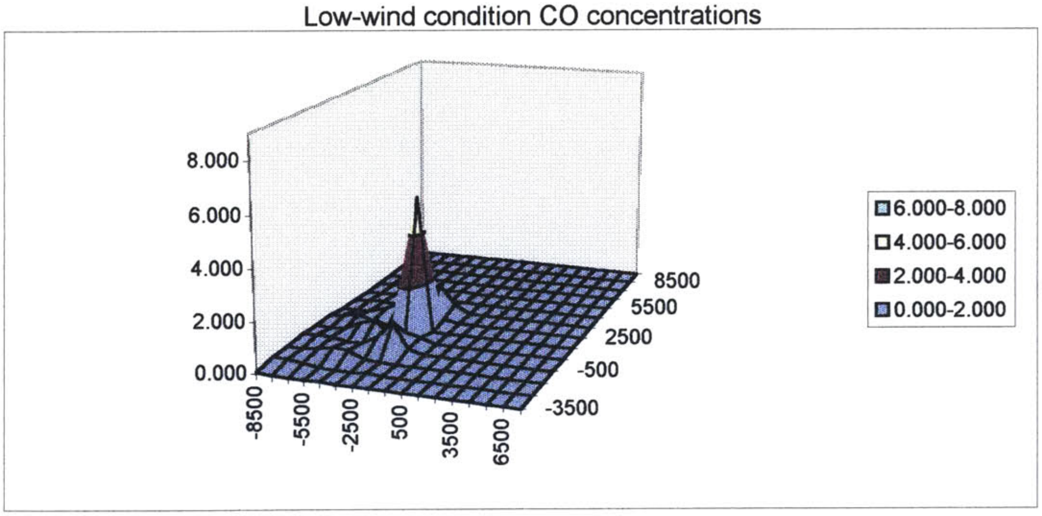
6 P.M.



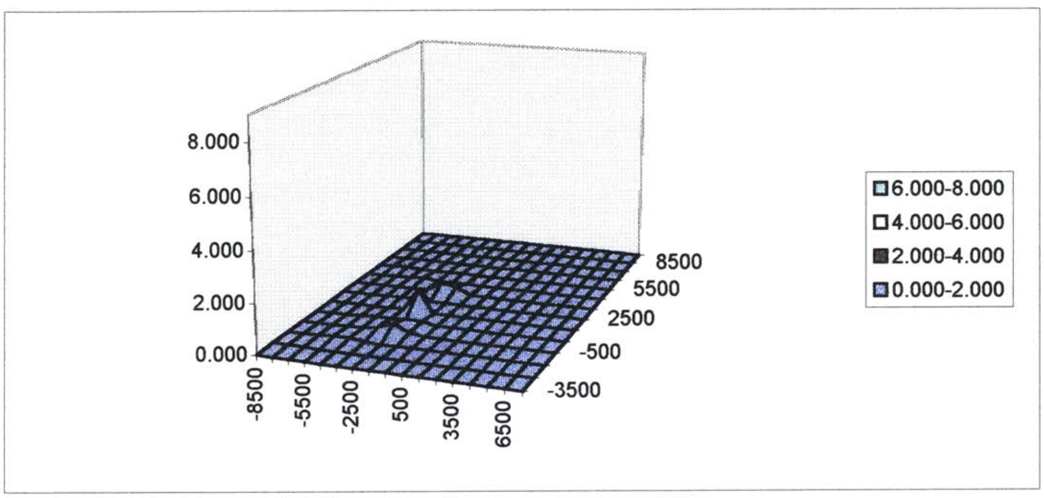
7 P.M.

*Peak concentrations are greater than 8.000 PPM

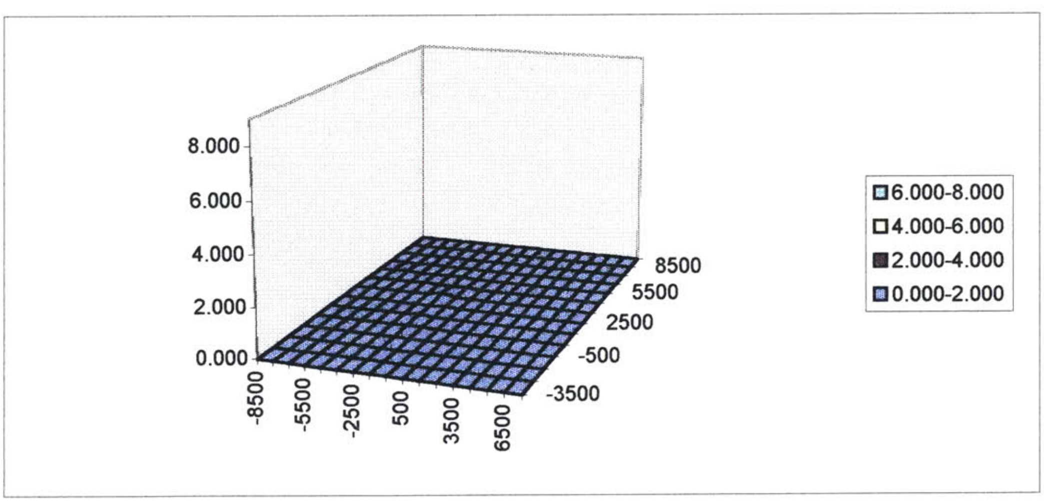
Low-wind condition CO concentrations



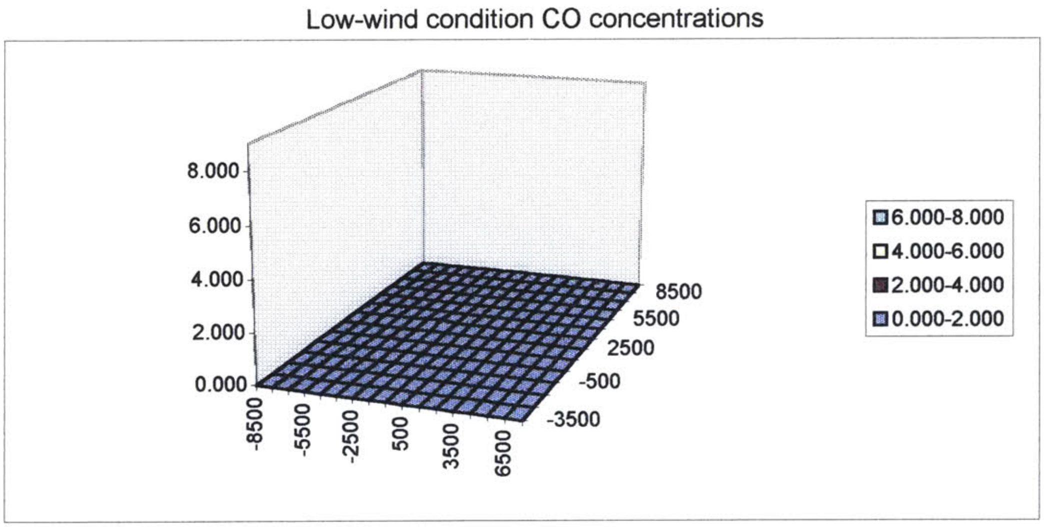
8 P.M.



9 P.M.

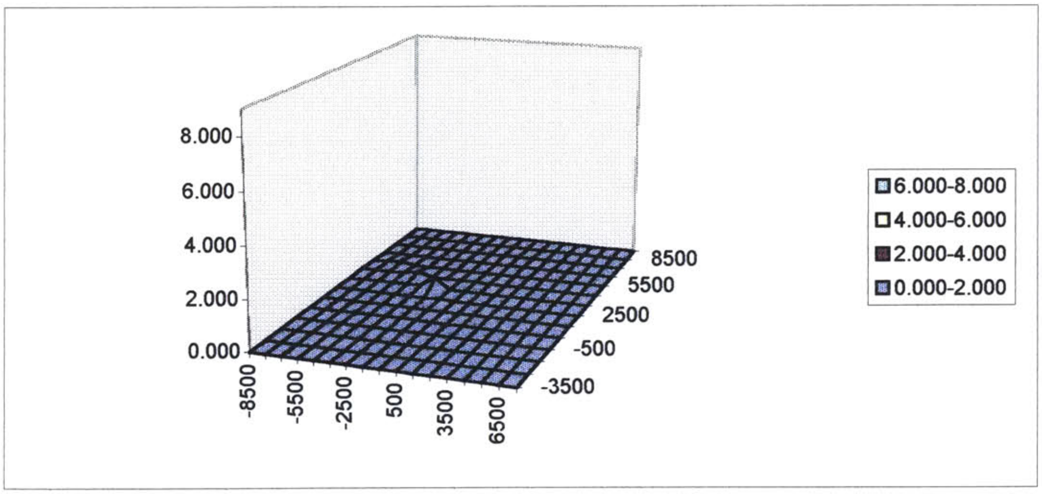


10 P.M.

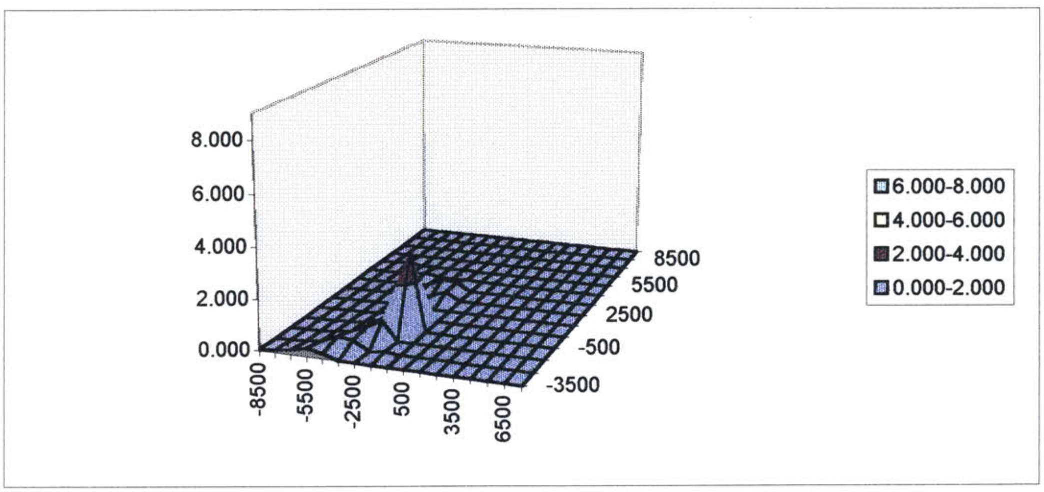

Low-wind condition CO concentrations
8.000
6.000
4.000
2.000
0.000
-8500
-5500
-2500
500
3500
6500
8500
5500
2500
-500
-3500
6.000-8.000
4.000-6.000
2.000-4.000
0.000-2.000

11 P.M.

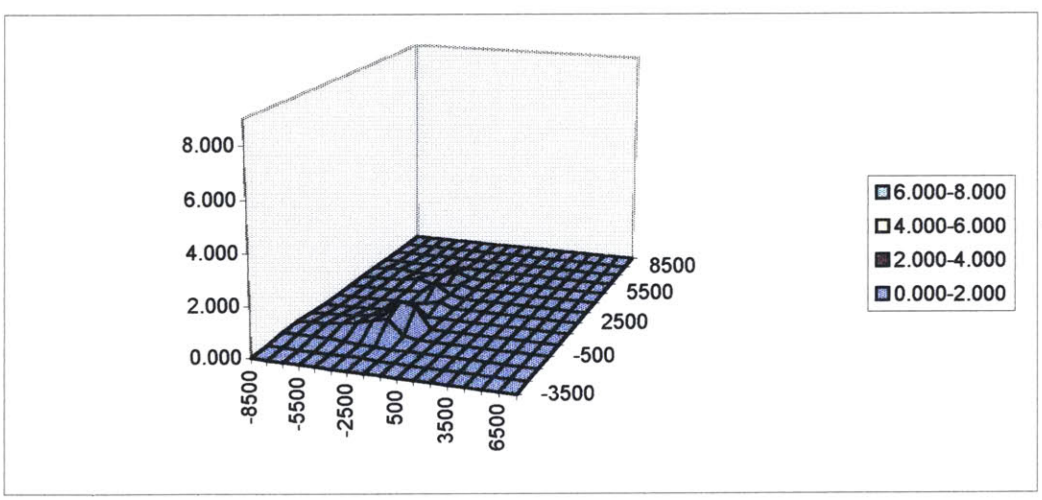
CO concentrations without GSE



5 A.M.

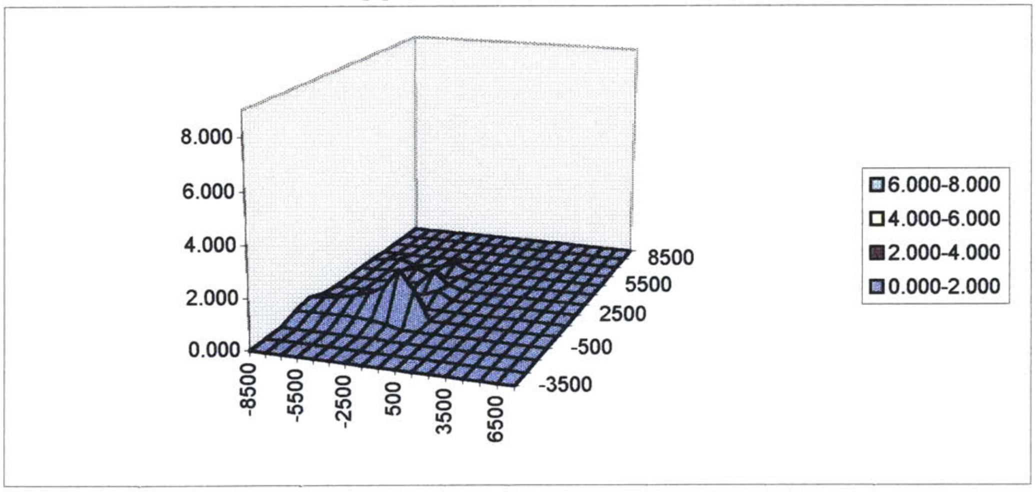


6 A.M.

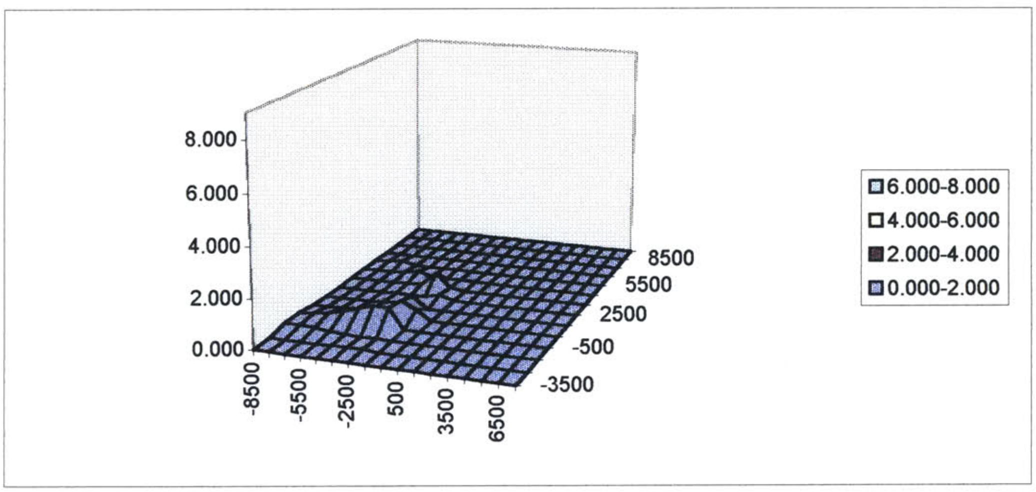


7 A.M.

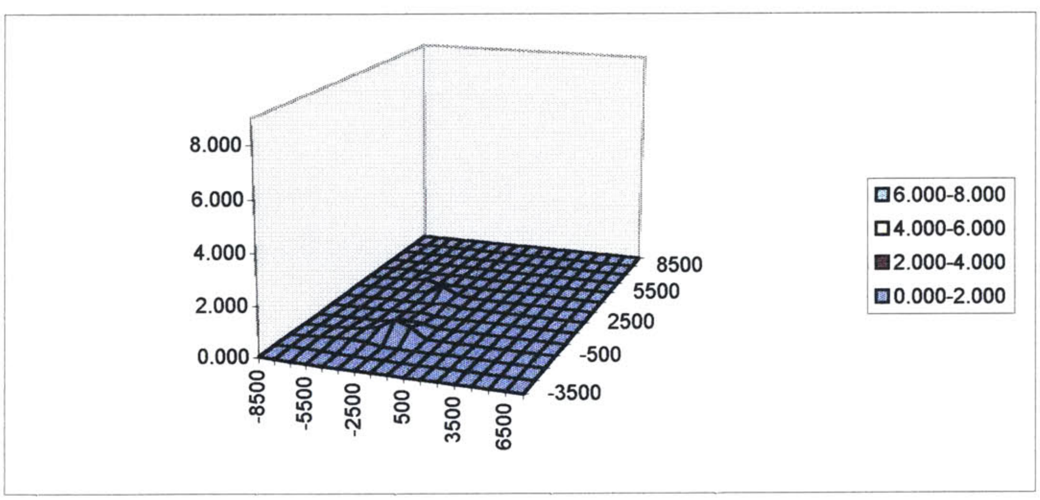
CO concentrations without GSE



8 A.M.

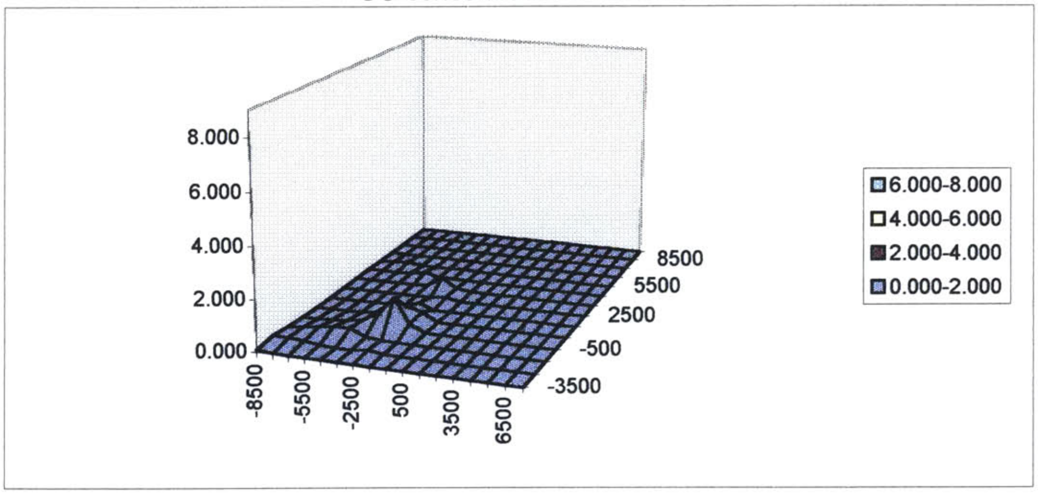


9 A.M.

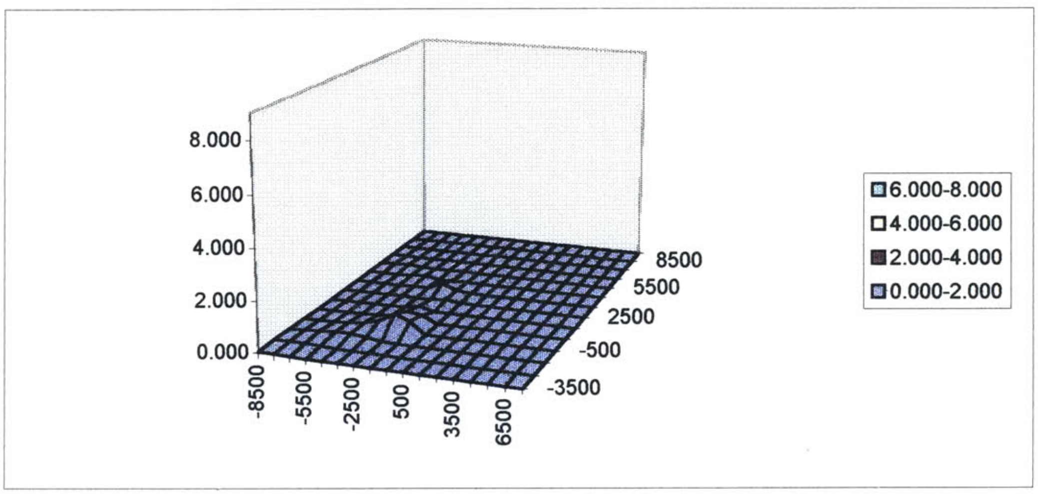


10 A.M.

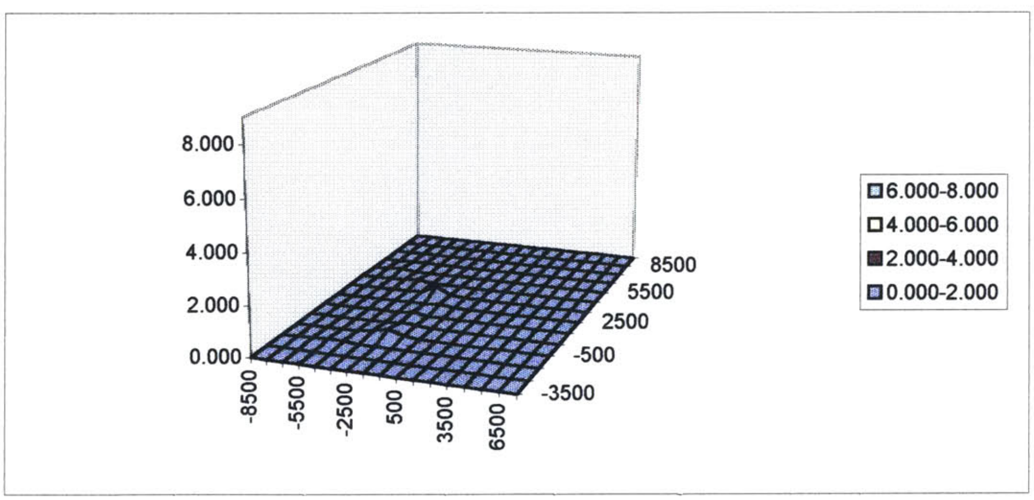
CO concentrations without GSE



11 A.M.

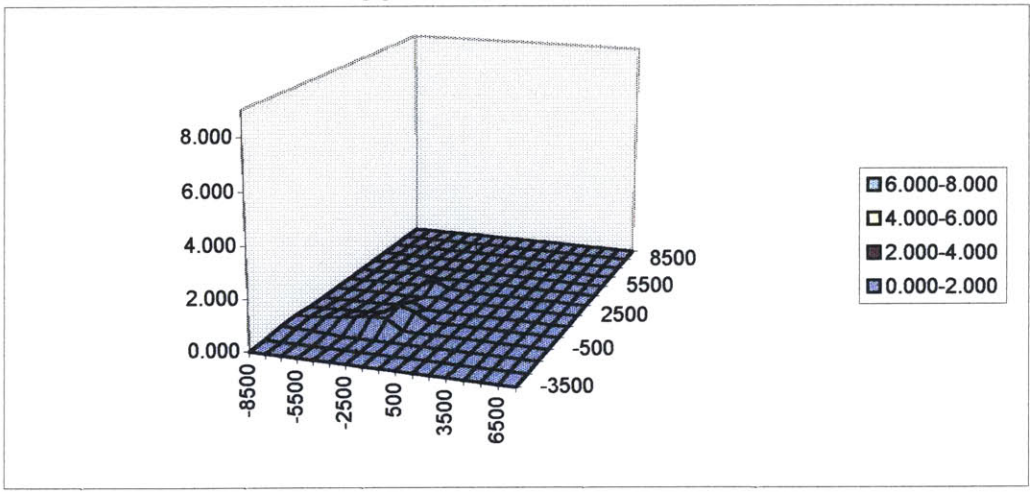


Noon

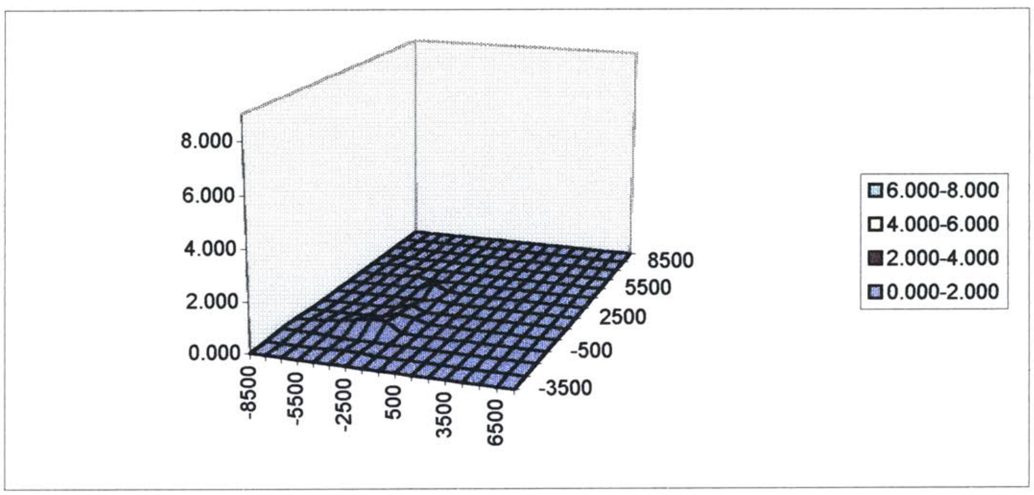


1 P.M.

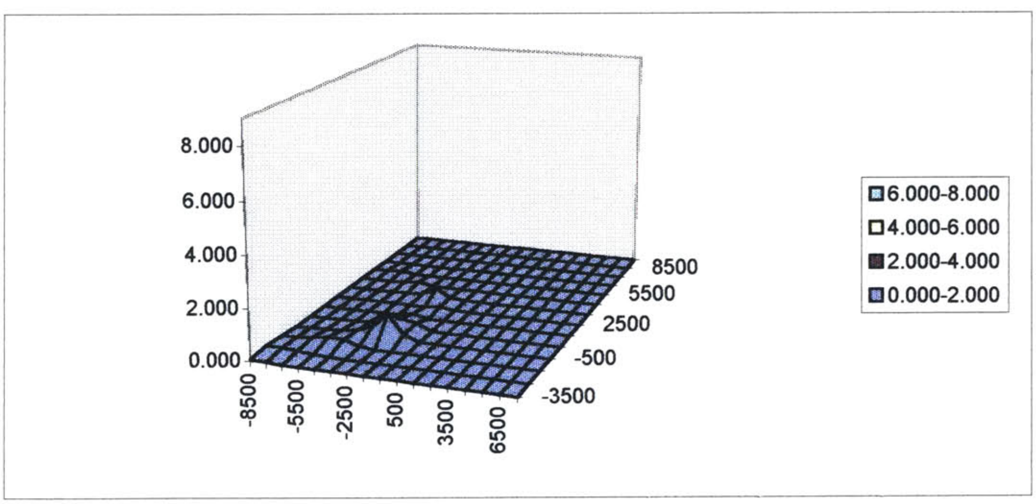
CO concentrations without GSE



2 P.M.

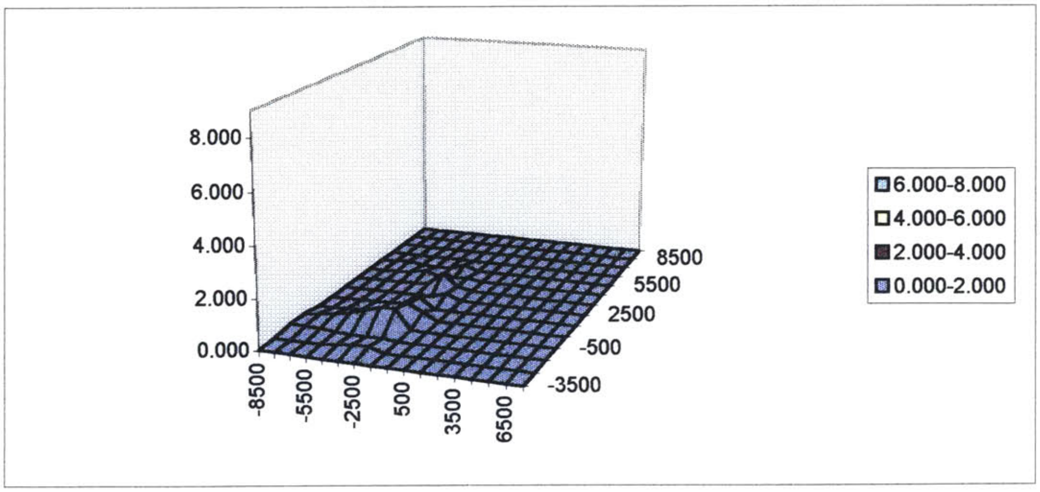


3 P.M.

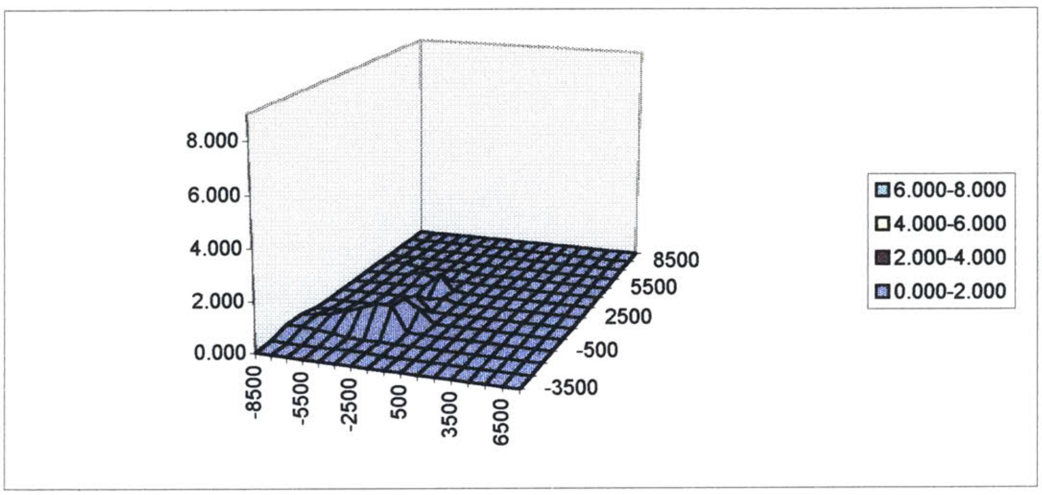


4 P.M.

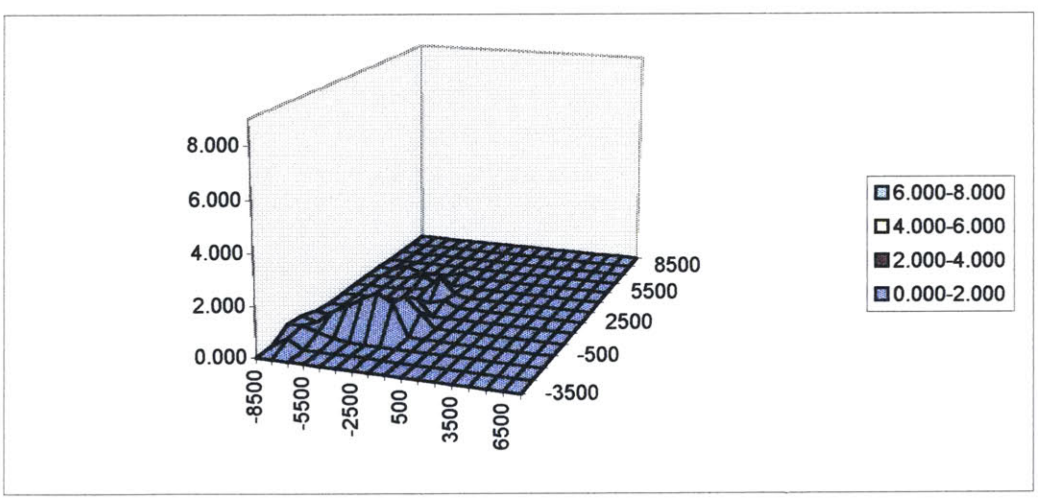
CO concentrations without GSE



5 P.M.

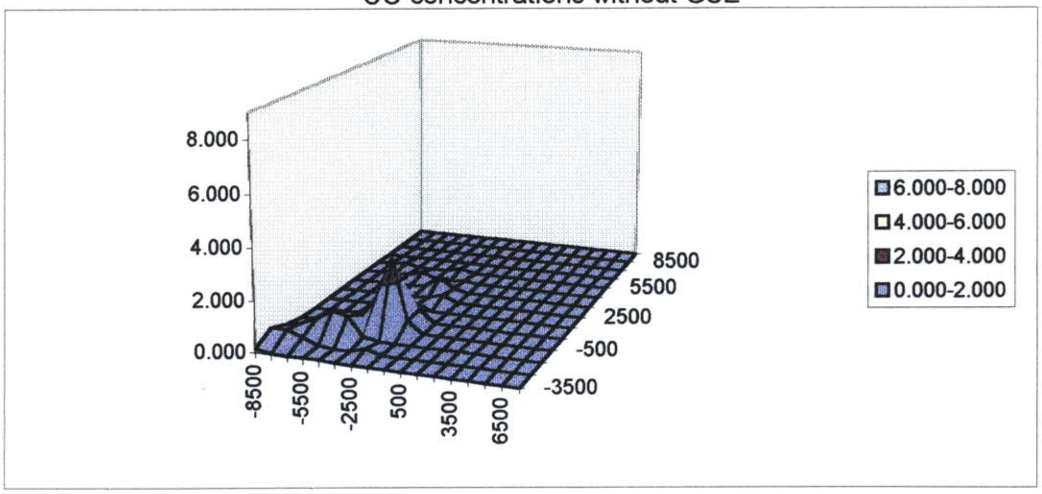


6 P.M.

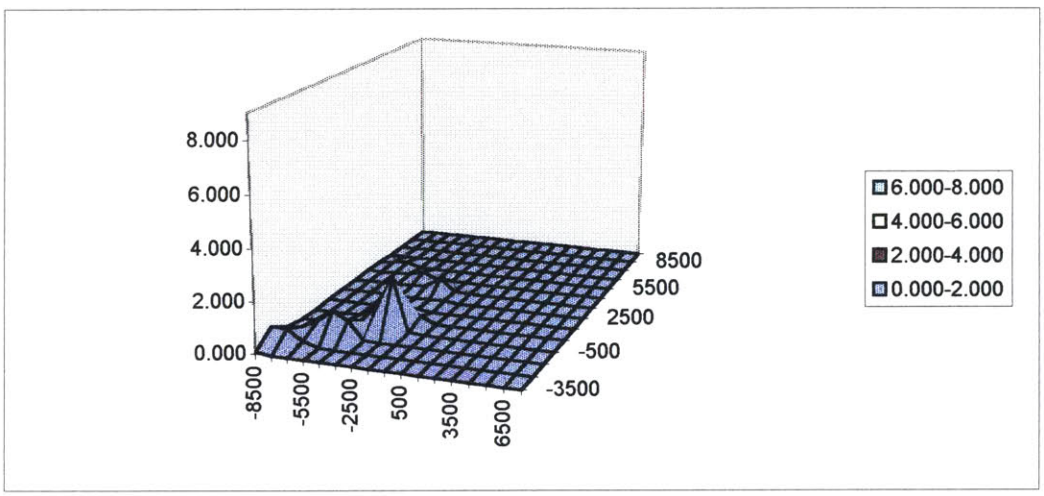


7 P.M.

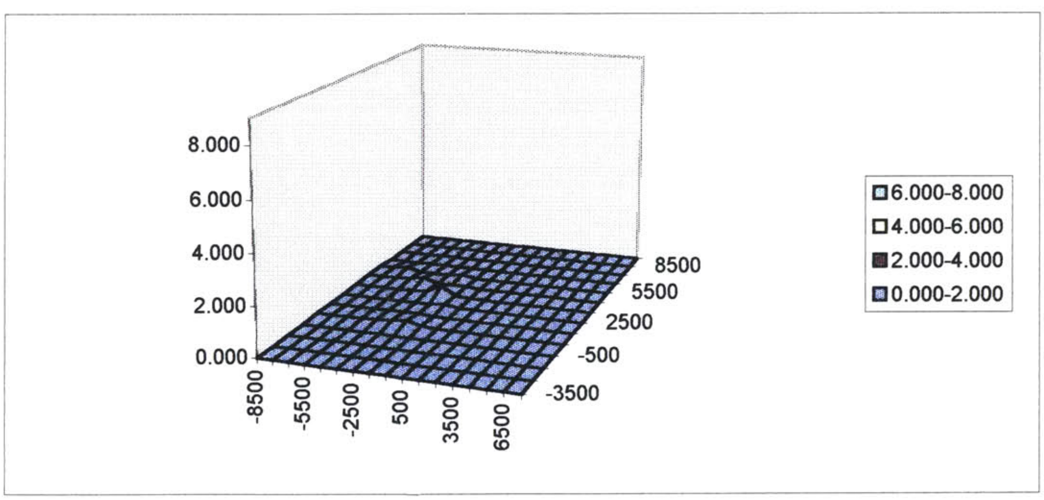
CO concentrations without GSE



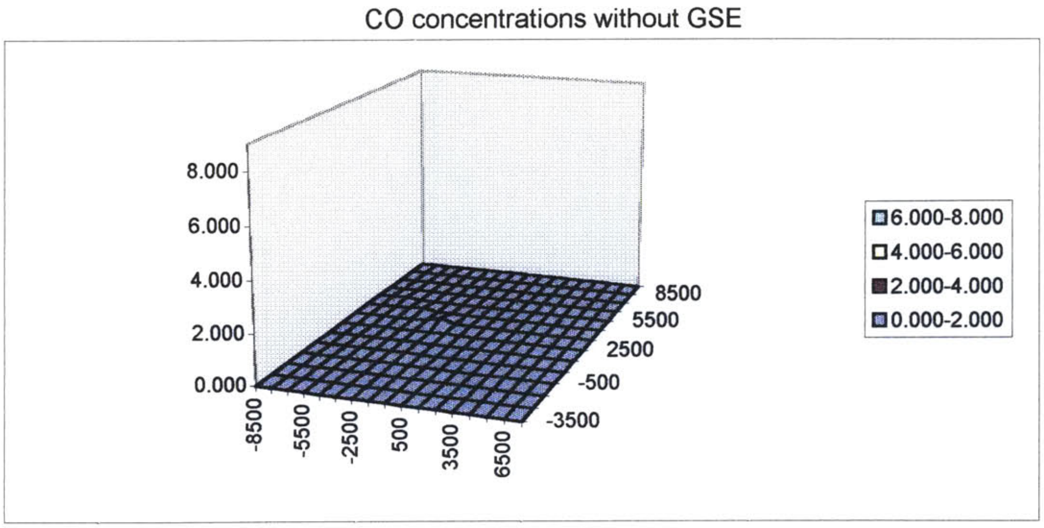
8 P.M.



9 P.M.

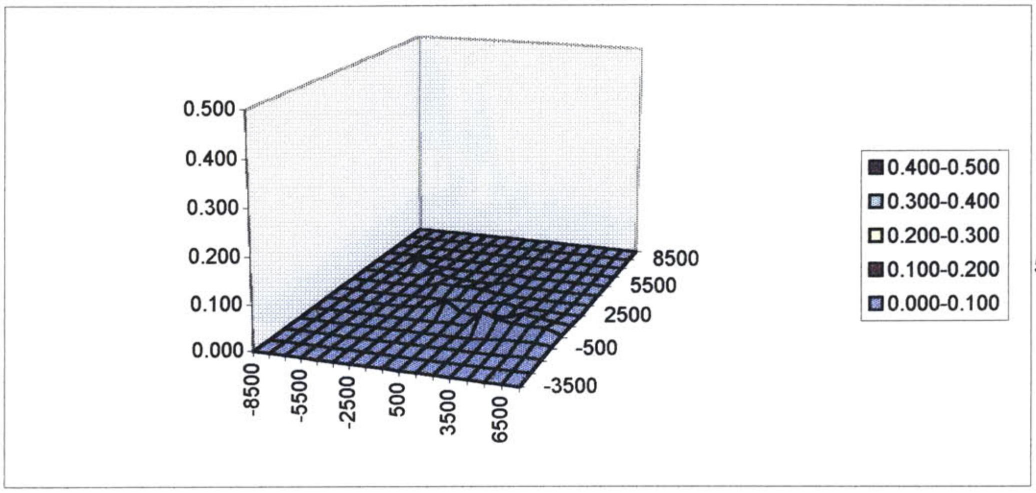


10 P.M.

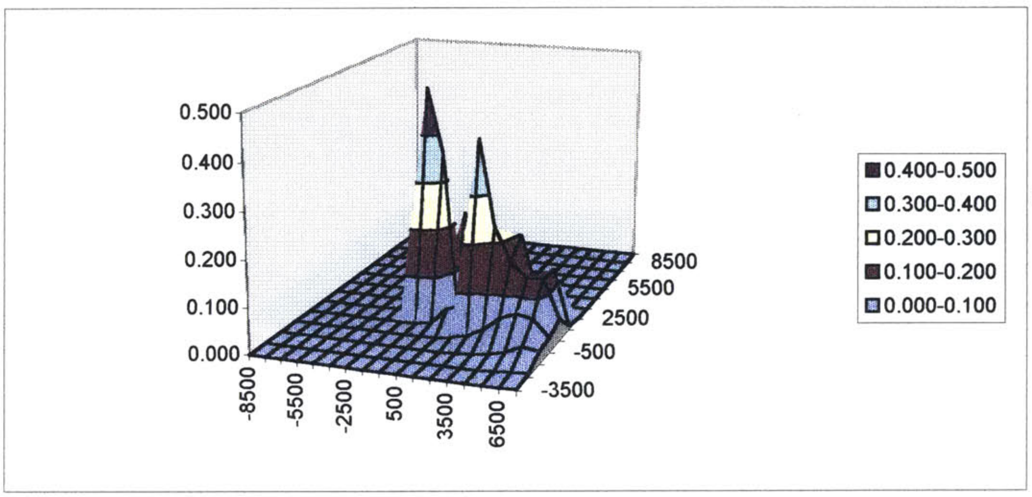

CO concentrations without GSE
8.000
6.000
4.000
2.000
0.000
-8500
-5500
-2500
500
3500
6500
8500
5500
2500
-500
-3500
6.000-8.000
4.000-6.000
2.000-4.000
0.000-2.000

11 P.M.

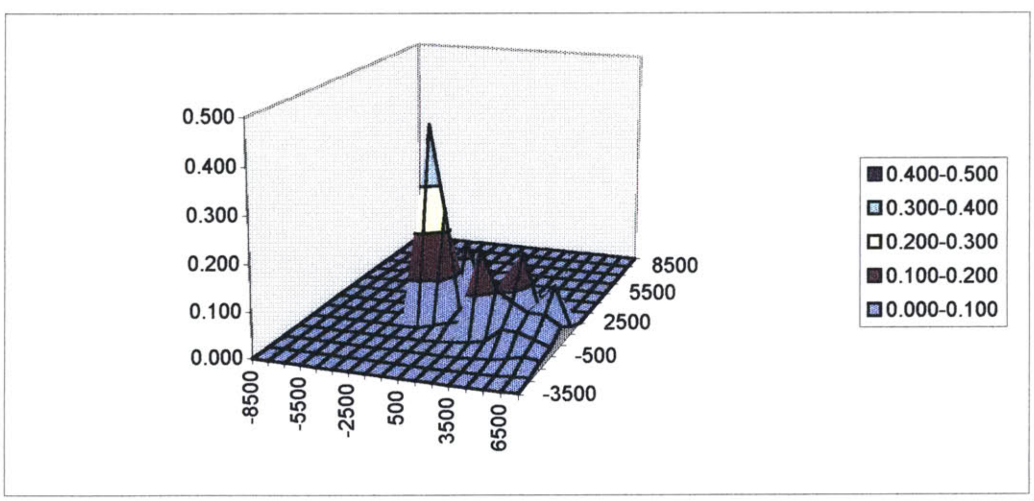
NO_X concentrations for alternative wind direction



5 A.M.



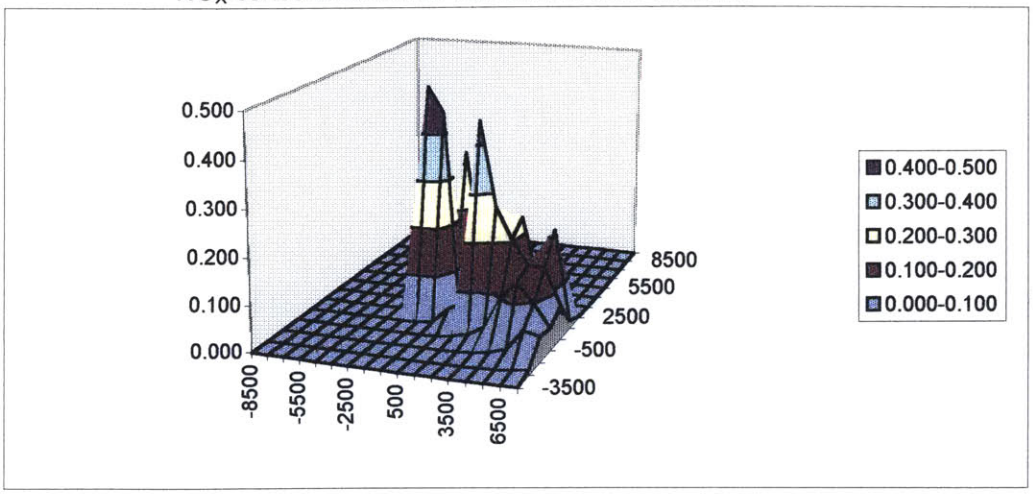
6 A.M.*



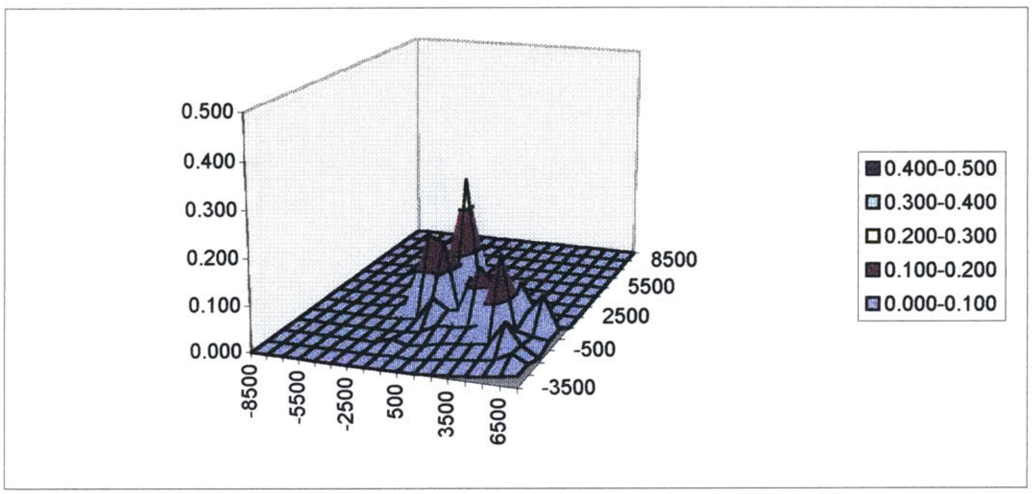
7 A.M.

*Peak concentrations are greater than 0.500 PPM

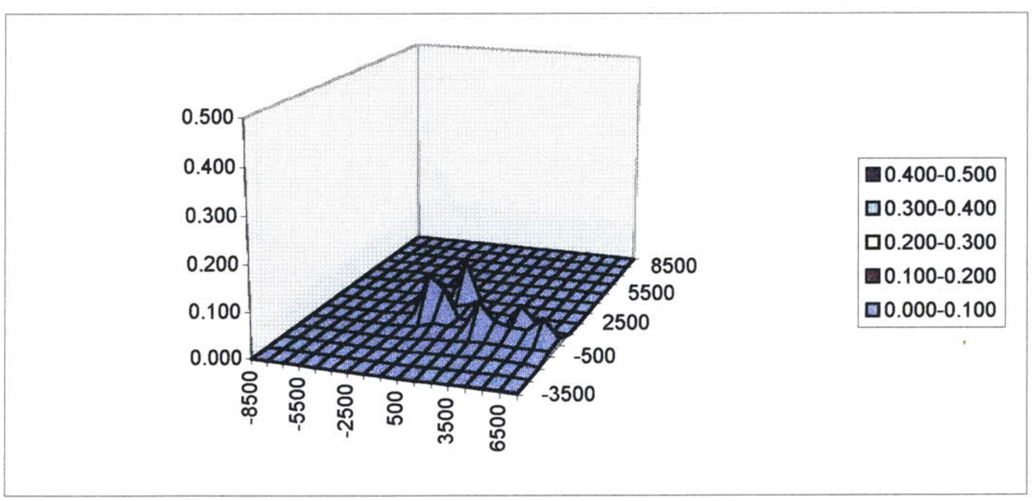
NO$_X$ concentrations for alternative wind direction



8 A.M.*



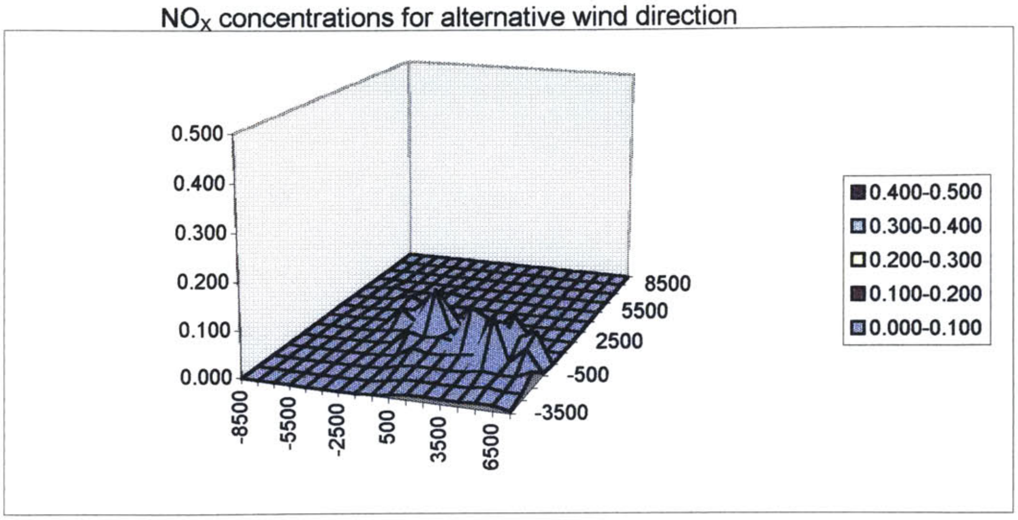
9 A.M.



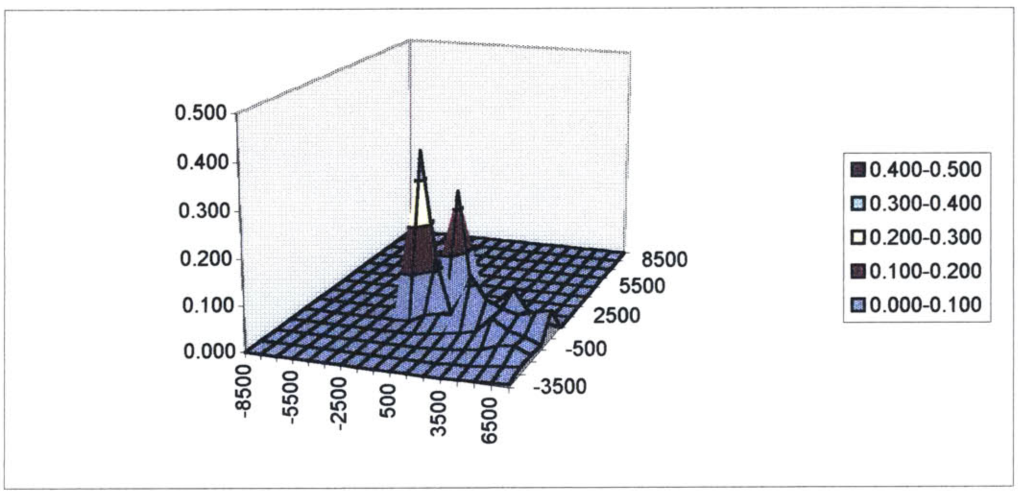
10 A.M.

*Peak concentrations are greater than 0.500 PPM

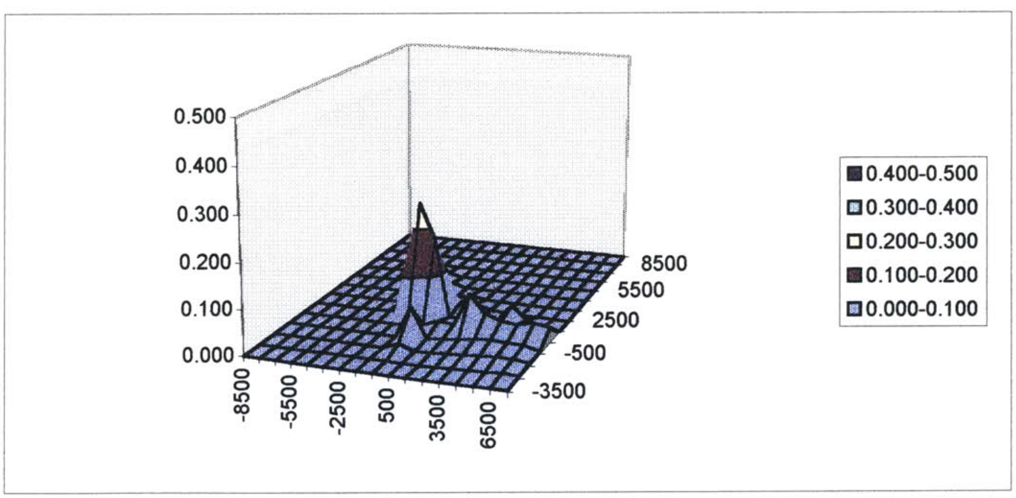
NO_X concentrations for alternative wind direction



11 A.M.

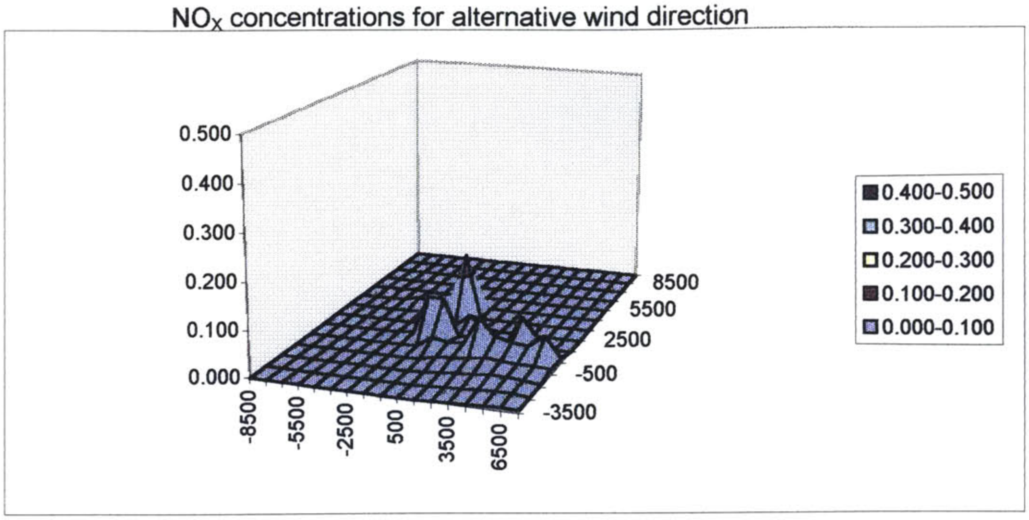


Noon

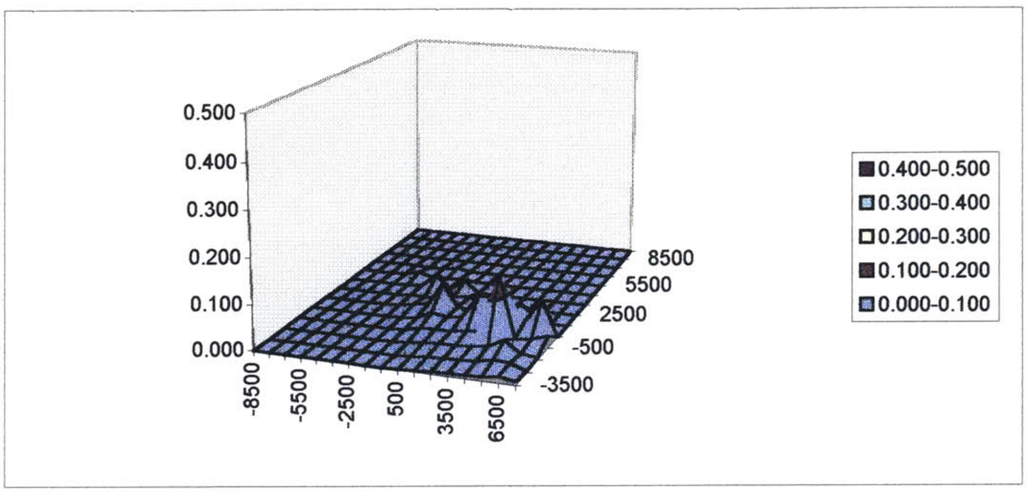


1 P.M.

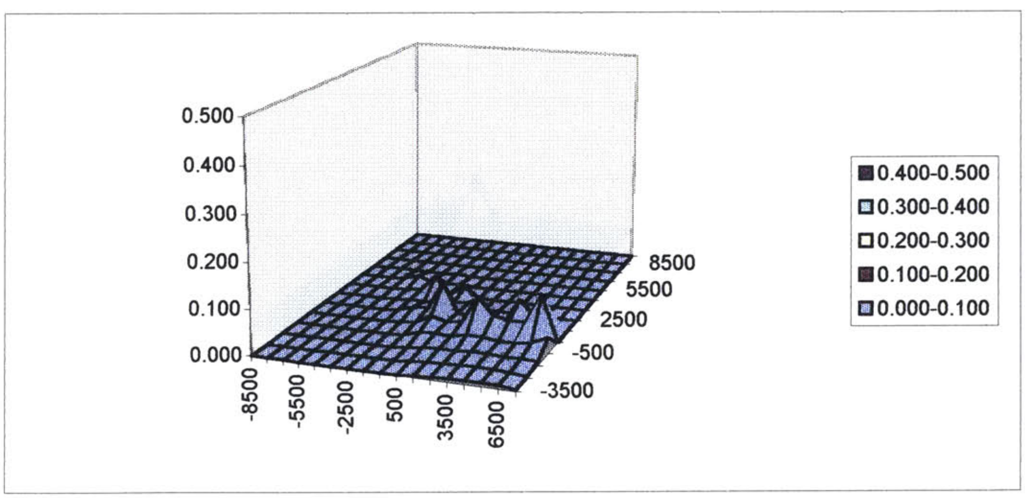
NO_x concentrations for alternative wind direction



2 P.M.

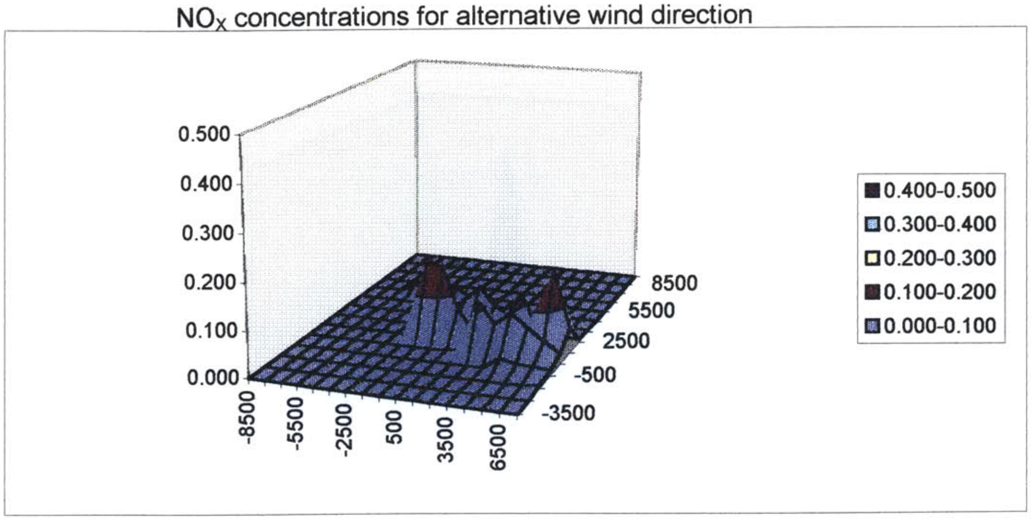


3 P.M.

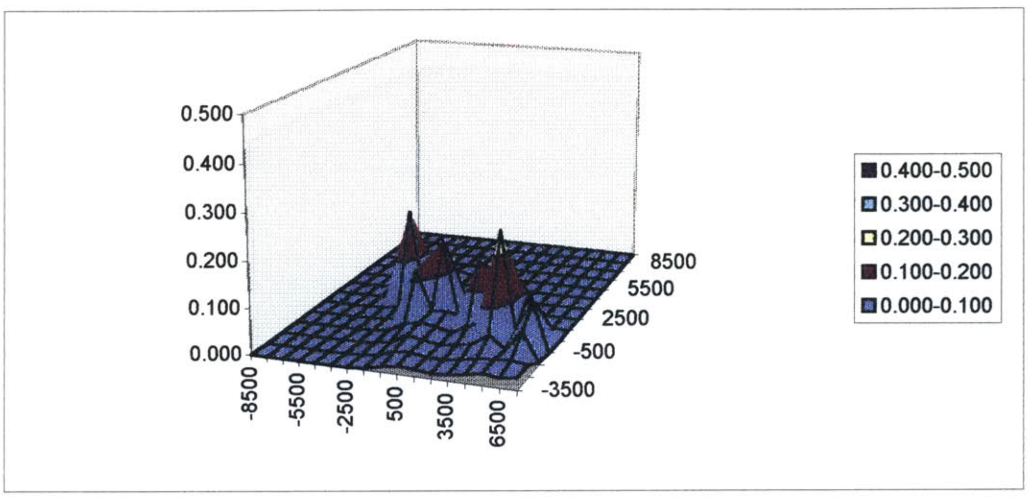


4 P.M.

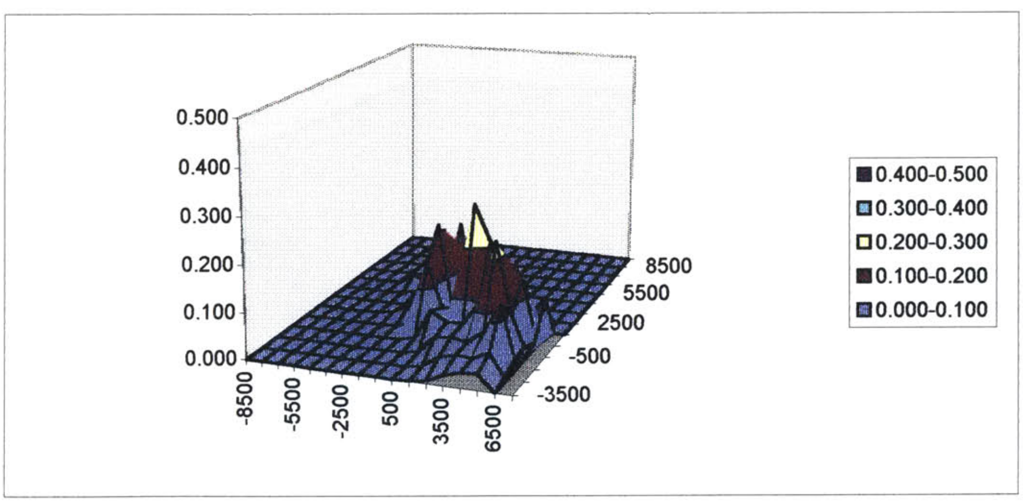
NO_X concentrations for alternative wind direction



5 P.M.

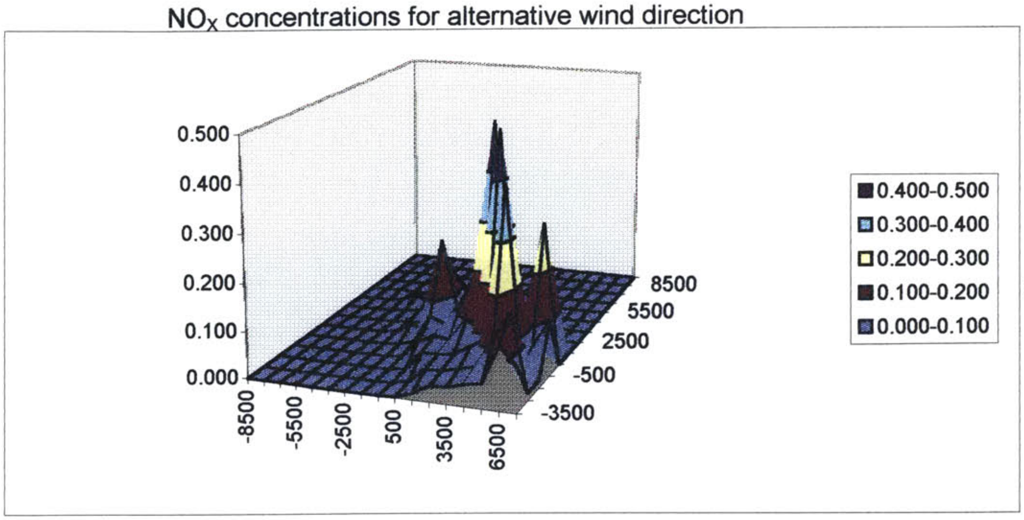


6 P.M.

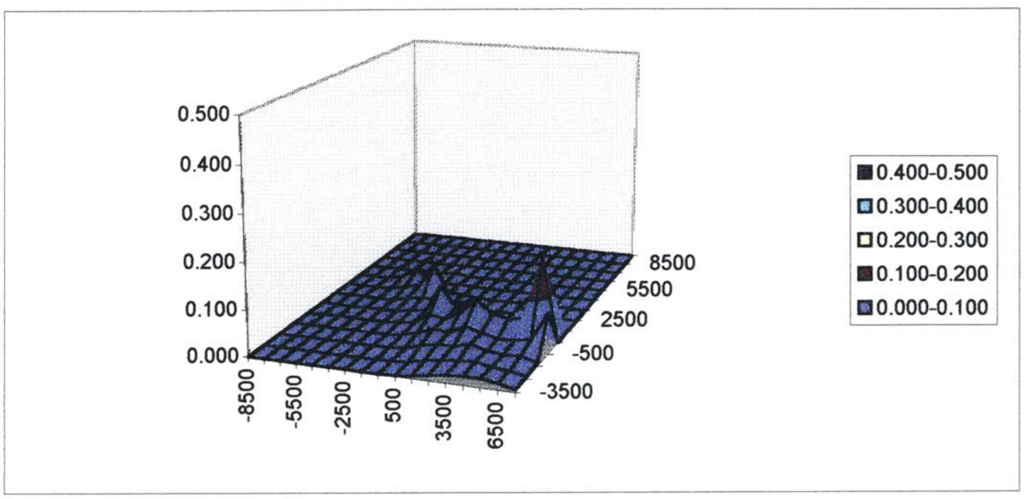


7 P.M.

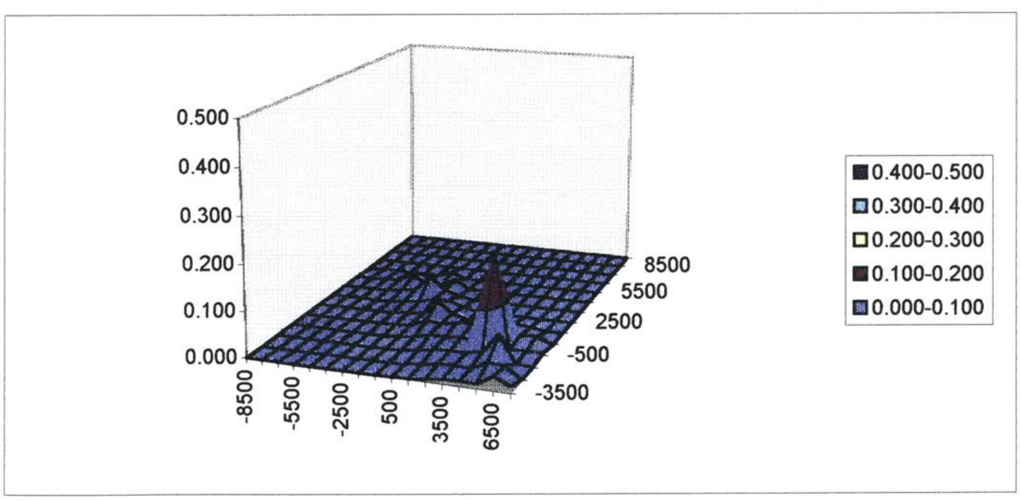
NO_X concentrations for alternative wind direction



8 P.M.*



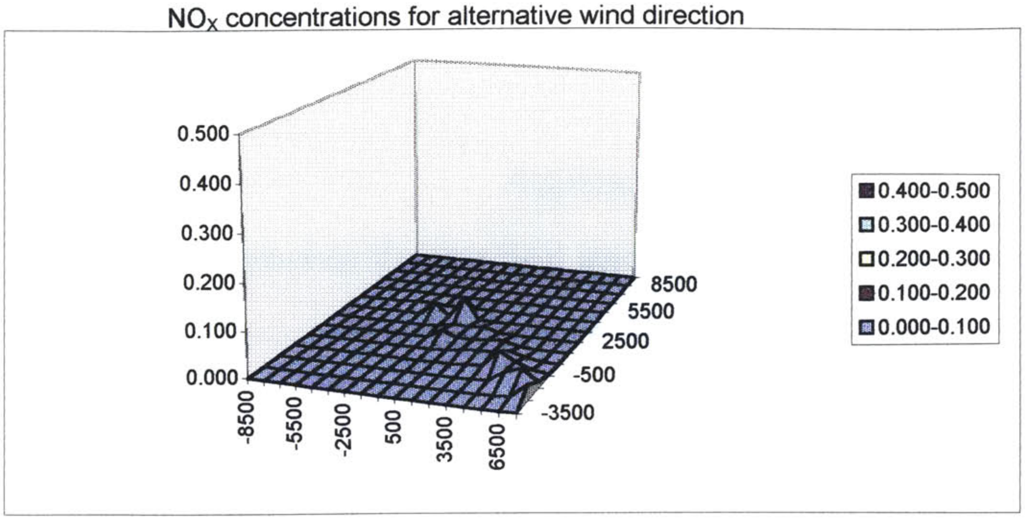
9 P.M.



10 P.M.

*Peak concentrations are greater than 0.500 PPM

NO_X concentrations for alternative wind direction



11 P.M.

Appendix J
Annual Emission Estimation and Dispersion Analysis Results for Future Scenarios

Estimated annual emissions from airport mobile sources, in tons of pollutant, for assumed future scenario in 2010.

(a) with no increase in traffic

Emission source Category	HC	CO	NO_X	SO_X	PM10
Aircraft	1190.64	4882.00	2001.15	108.54	N/A
Ground Support Equipment	103.30	4617.23	295.07	10.57	12.40
On-Road Vehicles	32.24	310.34	38.55	2.04	1.60
Total	1326.18	9809.57	2334.77	121.15	14.00

(b) with a 10% increase in traffic

Emission source Category	HC	CO	NO_X	SO_X	PM10
Aircraft	1309.77	5370.43	2201.40	119.40	N/A
Ground Support Equipment	113.64	5079.21	324.60	11.63	13.64
On-Road Vehicles	35.47	341.38	42.40	2.24	1.76
Total	1458.88	10791.02	2568.40	133.27	15.40

Hourly maximum concentrations result from dispersion calculation.

	NO_X			CO			SO_X		
	1999	2010	Increase	1999	2010	Increase	1999	2010	Increase
5 A.M.	0.082	0.090	9.76%	0.743	0.772	3.90%	0.001	0.001	0.00%
6 A.M.	0.400	0.440	10.00%	8.740	9.618	10.00%	0.021	0.022	9.52%
7 A.M.	0.218	0.226	9.63%	4.951	4.000	7.35%	0.006	0.007 **	16.67%
8 A.M.	0.244	0.265	9.84%	2.969	3.136	9.50%	0.015	0.015	6.67%
9 A.M.	0.266	0.282	9.40%	6.193	5.749	8.45%	0.007	0.007	0.00%
10 A.M.	0.098	0.104	10.20%	1.825	1.581	7.89%	0.004	0.005	25.00%
11 A.M.	0.224	0.235	9.38%	5.390	4.903	8.26%	0.010	0.010	10.00%
12 P.M.	0.112	0.122	9.82%	2.171	2.100	8.80%	0.005	0.005	0.00%
1 P.M.	0.134	0.144	9.70%	2.606	2.184	6.91%	0.004	0.004	25.00%
2 P.M.	0.125	0.131	8.80%	3.749	3.561	8.22%	0.004	0.004	0.00%
3 P.M.	0.133	0.143	9.02%	2.684	2.742	8.64%	0.003	0.004	33.33%
4 P.M.	0.158	0.170	9.49%	3.641	3.768	8.87%	0.006	0.007	16.67%
5 P.M.	0.224	0.238	9.38%	4.701	4.379	8.47%	0.006	0.006	0.00%
6 P.M.	0.325	0.341	9.54%	7.692	6.860	8.10%	0.009	0.009	11.11%
7 P.M.	0.398	0.434	9.80%	6.433	5.924	8.36%	0.014	0.014	7.14%
8 P.M.	0.482	0.515	9.75%	3.236	3.308 *	9.30%	0.018	0.019	11.11%
9 P.M.	0.196	0.200	9.18%	2.176	2.433	10.16%	0.010	0.010	10.00%
10 P.M.	0.034	0.034	2.94%	0.436	0.443	1.38%	0.003	0.003	33.33%
11 P.M.	0.020	0.020	0.00%	0.248	0.252	1.61%	0.001	0.001	0.00%

* The maximum concentration for CO occurred at (-2500,1500) for 1999 and (-2500,-500) for 2010.

** The maximum concentration for SO_X occurred at (-2500, 1500) for 1999 and (-2500,500) for 2010.

References

Airguide Publications, Inc., 2000. *Flight Guide Airport and Frequency Manual Vol. III, Eastern States.* Long Beach, CA

Commonwealth of Massachusetts, Executive Office of Environmental Affairs. Air quality data for East Boston, September 1999, obtained via facsimile.

DHL Airways, 1999. *Winter 1999/2000 Schedule*, Cincinnati, OH

Exxon Company, International, 1999. *Turbine-Engined Fleets of the World's Airlines.* Prepared by Aviation Data Service, Inc., Florham Park, NJ.

Gallagher, Mark J., 2000. Personal communication regarding jet engine maintenance.

Godish, Thad, 1997. *Air Quality 3rd ed.* Lewis Publishers, New York, NY.

Klee, Ulrich, 1999. *JP Airline-Fleets International 1999/2000.* Bucher & CO., Publikationen, Zurich.

Massachusetts Port Authority, *Boston-Logan International Airport Monthly Airport Traffic Summary - May 1999.* Electronically obtained from Massachusetts Port Authority via World Wide Web.

Massachusetts Port Authority, 1999. *Logan Airside Improvements Planning Project - Draft Environmental Impact Statement/Report Executive Summay.*

Natural Resources Defense Council, 1996. *Flying Off Course - Environmental Impacts of America's Airports.* New York, NY.

OAG Worldwide, *OAG Pocket Flight Guide - North America September 1999, Vol.30, No.9,* 1999. OAG Worldwide, Oak Brook, IL.

OAG Worldwide, *OAG Flight Guide - Worldwide October 1999, Vol.1, No.4*, 1999. OAG Worldwide, Oak Brook, IL.

Pavaux, Jacques, 1995. *Air Transport: Horizon 2020 - Key Factors and Future Prospects.* Les Presses De L'Institute Du Transport Aerien, Paris, France.

Schnelle, Karl B., Dey, Partha R., 2000. *Atmospheric Dispersion Modeling Compliance Guide*, McGraw-Hill Co., New York, NY.

Thrasher, Ted, 2000. Personal communication regarding EDMS.

U.K. Ministry of Defence, Defence Evaluation and Research Agency, *Aircraft Engine Exhaust Emissions Data Bank*. Obtained electronically from Defence Evaluation and Research Agency via World Wide Web.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *Surface Observation Data for 1999 Boston Logan International Airport*. Obtained electronically from National Oceanic and Atmospheric Administration via E-mail.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1975. *Surface Observation TDF14 Documentation Manual*. Asheville, NC.

U.S. Department of Transportation, Federal Aviation Administration, 1999. *Aerospace Forecasts Fisical Years 2000-2011 (March 2000)*. Obrained electronically from Federal Aviation Administration via World Wide Web.

U.S. Department of Transportation, Federal Aviation Administration, 1997. *Emissions and Dispersion Modeling System (EDMS) Reference Manual*. FAA-AEE-97-01.

U.S. Department of Transportation, Federal Aviation Administration, *Federal Aviation Administration Engine Emission Database (FAAEED)*. Obtained electronically from Federal Aviation Administration via E-mail.

U.S. Department of Transportation, Bureau of Transportation Statistics, 1999. *Airport Activity Statistics of Certificated Route Air Carriers, Twelve Months Ending December 31, 1998*. BTS99-05, Washington, DC.

U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Mobile Sources, Office of Air Quality Planning and Standards, 1992. *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources. EPA-450/4/81-026d (Revised)*, Ann Arbor, MI, Research Triangle Park, NC for Office of Air Quality Planning and Standards.

U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. *National Ambient Air Quality Standards*. Obtained electronically from Environmental Protection Agency via World Wide Web.

U.S. Environmental Protection Agency, Office of Mobile Sources, 1999. *Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft*. Prepared by ICF Consulting Group, EPA420-R-99-013, Ann Arbor, MI.

U.S. Environmental Protection Agency, Office of Mobile sources, 1999. *Technical Support for Development of Airport Ground Support Equipment Emission Reductions*. Prepared by Sierra Research, Inc., EPA420-R-99-007, Ann Arbor, MI.

White, Frank M., 1991. *Viscous Fluid Flow, 2nd ed.* McGraw-Hill, Inc., New York, NY.